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Mine Drainage and Surface Mine Reclamation

Proceedings of a conference sponsored by The American Society for Surface Mining and Reclamation, The Bureau of Mines, and The Office of Surface Mining Reclamation and Enforcement. The conference was held in Pittsburgh, Pennsylvania on April 19-21, 1988.

Volume II: Mine Reclamation, Abandoned Mine Lands and Policy Issues.

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UNITED STATES DEPARTMENT OF THE INTERIOR

Information Circular 9184

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Volume II: Mine Reclamation, Abandoned Mine Lands and Policy Issues.

Volume I: Mine Water and Mine Waste, is also available from The Bureau of Mines as Information Circular 9183.

UNITED STATES DEPARTMENT OF THE INTERIOR
Donald Paul Hodel, Secretary

BUREAU OF MINES
David S. Brown, Acting Director

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

With Factors for Conversion to U.S. Customary Units and the International System of Units (SI)[1]

Abbreviation or unit	Unit of measure	To convert to--	Multiply by--
acre	acre	hectares	0.405
bar	bar	NA	
bu	bushel	NA	
C	coulomb	NA	
cm	centimeter	inches	0.3937
eV	electron volt	NA	
ft	foot	meters	0.3048
ft^2	square foot	square centimeter	929.0
ft^3	cubic foot	cubic meters	0.028
ft/s	foot per second	centimeters per second	30.48
g	gram	ounces	0.0353
gal	gallon	liters	3.785
gal/h	gallon per hour	liters per hour	3.785
gal/min	gallon per minute	liters per minute	3.785
h	hour	NA	
ha	hectare	acres	2.471
in	inch	centimeters	2.54
K	kelvin	NA	
kg	kilogram	pounds	2.205
L	liter	cubic inches	61.025
lb	pound	kilograms	0.4536
lb/min	pounds per minute	kilograms per minute	0.4536
L/min	liter per minute	gallons per minute	0.2642
m	meter	feet	3.28
$\underline{M}$	mole per liter		
$\overline{M}$	mega	NA	
m^3	cubic meter	cubic yards	1.308
m^3/s	cubic meter per second	gallons per second	264.2
mil	mil	inch	0.001 inch
mile	mile	kilometers	1.609
mg	milligram	grains	0.0154
mg/L	milligram per liter	NA	
mg/(L·h)	milligram per liter per hour	NA	
min	minute	NA	
mL	milliliter	cubic inches	0.061
mm	millimeter	inches	0.0394
mmho/m	millimho per meter	NA	
mol	mol	NA	
mol/L	mole per liter	NA	
mV	millivolt	NA	
μm	micrometer	inches	3.94×10^{-5}
ohm	ohm	NA	
pct	percent	NA	
psi	pound per square inch	grams per square centimeter	70.307
std ft^3/min	standard cubic foot per minute	NA NA	
ton	ton	metric tons	0.907
yr	year	NA	

NA Not applicable.

[1] Owing to the preference of individual authors, U.S. customary and SI units have both been used in this report. Conversion factors are provided for the assistance of the reader.

MINE DRAINAGE AND SURFACE MINE RECLAMATION

Proceedings of a Conference jointly sponsored by the Bureau of Mines, the Office of Surface Mining Reclamation and Enforcement, and the American Society of Surface Mining and Reclamation.

ABSTRACT

Mine waste and mine reclamation are topics of major interest to the mining industry, the government and the general public. This publication and its companion volume are the proceedings of a conference held in Pittsburgh, April 19-21, 1988. There were nine sessions (50 papers) that dealt with the geochemistry, hydrology and problems of mine waste and mine water, especially acid mine drainage. These comprise Volume 1. The nine sessions (43 papers) that dealt with reclamation and restoration of disturbed lands, as well as related policy issues, are included in volume 2. Volume 2 also contains the ten papers that pertained to control of subsidence and mine fires at abandoned mines. Poster session presentations are, in general, represented by abstracts; these have been placed in the back of both volumes.

Reference to companies and specific products in these papers does not imply endorsement by the Bureau of Mines.

THE USE OF WARM SEASON GRASSES FOR REVEGETATING SANDS AND GRAVELS IN NEW HAMPSHIRE, VERMONT, AND NEW YORK

John Dickerson, Theodore Kelsey, and Raymond Godfrey[1]

Abstract.--Sand and gravel mines and other droughty sites were planted with warm season (C_4) grasses as single species plots and mixtures. Treatments included planting methods, i.e. drilling, broadcasting with bulldozer "tracking", and hydroseeding. Nitrogen was applied as urea, ammonium nitrate, or isobutylidene diurea. Plantings of C_4 grass mixtures with legumes were evaluated after one year's growth. C_4 grass cultivars and species with best growth and percent cover at 6, 18, and 30 months after planting were 'Blackwell' switchgrass (*Panicum virgatum* L.), 'Niagara' big bluestem (*Andropogon gerardi* Vitman), 'Aldous' little bluestem [Schizachyrium scoparium (Michx.) Nash], and 'Goldstrike' sand bluestem (*Andropogn hallii* Hack.). Indiangrass (*Sorghastrum nutans* (L.) Nash), sideoats grama [*Bouteloua curtipendula* (Michx.) Torr.], and deertongue (*Dichanthelium clandestinum* (L.) Gould) were less successful species. Nitrogen applied in slow release form appeared to benefit seedling development of switchgrass and sand lovegrass (*Eragrostis trichodes* (Nutt.) Wood) on a sand bank during the first growing season. No-till drilling and broadcasting with incorporation by bulldozer tracking were successful methods of planting C_4 grasses on droughty sites. At one location, inclusion of hairy vetch (*Vicia villosa* Roth) with the C_4 grasses resulted in improved first year ground cover.

INTRODUCTION

Sand and gravel borrow pits cover about 200,000 acres in Pennsylvania, New York, and the New England states (USDA-SCS 1981). In most operations the overburden material is seldom stockpiled for reclamation. After mining ceases, the extremely droughty spoils on these sites strongly inhibit the reestablishment of indigenous vegetation. A rapid transition from biennial and perennial plants (Andreae and Cavers 1981) to very open stands of birch (*Betula* spp.) and pine (*Pinus* spp.) is common with very little soil profile development. The few trees that result are stunted, low value specimens which accumulate most of the very limited onsite nutrients in their biomass (Odum 1971). Excessive drainage, very low organic matter, and low percentage of soil fines further inhibit herbaceous plant establishment.

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[1] John Dickerson is Plant Materials Specialist for NY, VT, NH, and ME for the USDA-Soil Conservation Service, Syracuse, NY, and Theodore Kelsey and Raymond Godfrey are Resource Conservationists for the USDA-SCS in Durham, NH and Winooski, VT, respectively.

Typically, when seedings are made to revegetate these mines, mixtures include such species as ryegrass (*Lolium perenne* L. and *L. multiflorum* Lam.), Kentucky bluegrass (*Poa pratensis* L.), and red or tall fescue (*Festuca rubra* L. or *F. arundinacea* Schreb.). Good initial establishment usually results when a timely, well mulched seeding receives fertilizer and favorable rainfall. Unfortunately, the lush growth declines to a sparse plant population within 3 to 4 years, resulting in the need for replanting. The need for effective cover led to a series of test plantings throughout New England and New York in 1975-1977 (Gaffney and Dickerson 1987). Of the materials tested in that study, native warm-season (C_4)[2] grasses were superior to cool-season (C_3)[2] grasses and legumes for establishing effective, long-term cover, where surface layer fines[3] were below 15 percent.

Though C_4 grasses were superior, only a few species and cultivars were tested, and their cover developed slowly. Generally they required 3-4 years to become effective. Objectives of this study were: 1) to identify species and cultivars of C_4 grasses that are suited for reclamation of sand and gravel spoils in New England and New York, and 2) to determine agronomic practices that would promote rapid establishment of effective grass cover.

STUDY METHODS

Ten field plantings were made in New Hampshire, Vermont, and New York from 1984 to 1987 (table 1). Cultivars of several C_4 grass species were compared in replicated tests at two sites. Seven sites were sown with mixtures of species and a number of different agronomic practices were compared. The final planting was a replicated fertility trial on a droughty sand roadbank. The methods used at each location are described below and in table 1. Species and cultivars for each site are listed in tables 2 and 3.

Franklin Falls and Ossipee, NH, Small Plots

Warm-season grass evaluation plantings were established in Franklin and Ossipee, New Hampshire in 1984 and 1985 respectively.

The Franklin site is located on the Franklin Falls flood control dam borrow area. This area was stripped in the 1938 to 1943 era. The only vegetation occupying the site in 1984 was lichen, a few birch (*Betula* spp.) and stunted white pine (*Pinus strobus* L.) trees. In May, 1984, a planting site of 1/4 acre was back-dragged with a dozer and seeded to selected warm season grasses. The test consisted of 13 entries seeded in 12 ft. by 19 ft. plots, replicated twice. Species and cultivars used are listed in table 2.

Table 1.—Ten plantings made in New Hampshire, Vermont, and New York during 1984-1987.

Location	Date Planted	Type of Site	Gravel	Sand	Fines	pH	Planting Type	Method of Planting	No. of Varieties
				Percent[a]					
Franklin Falls,NH	4/84	Borrow pit	23	75	2	5.0	monoculture, small plots	broadcast,raked in, mulched	13
Ossipee,NH	5/85	Borrow pit	11	87	2		monoculture small plots	broadcast, raked in	13
Franklin Falls,NH	4/84	Borrow pit	23	75	2	5.0	monoculture large plots	drilled, mulched	4
Bennington,VT	5/13/85	Commercial mine	56	35	9	7.2	mixture large plots	broadcast, tracked in	-
Alton,NH	6/84	Sand bank					mixture large plots	hydroseeded	-
S.Woodbury,VT	6/5/85	Commerical mine	31	52	17	7.2	mixture large plots	broadcast, tracked in	3
Bennington,VT	5/8/87	Sand & Gravel mine	34	54	12	6.6	grass/legume mixture,large plots	broadcast, tracked in	10
Watson, NY	5/20/87	Borrow pit					grass/legume mixture,large plots	broadcast, tracked in	8
Speculator,NY	5/22/87	Borrow pit	6	84	10	5.4	grass/legume mixture,large plots	broadcast, tracked in	8
Concord,NH	4/22/87	Sand bank	7	91	2	5.2	grass mixture fertility plots	broadcast, raked in	6

[a] Percent by weight in surface 4" passing 200-mesh sieve.

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[2] C_3 and C_4 refer to photosynthetic pathways which determine the seasonality of plant growth.

[3] Percent by weight passing a 200-mesh sieve.

Table 2.—Species and cultivars used in two small plot trials in Ossipee and Franklin Falls, NH

Species		Cultivars	Origin	Developed At
Switchgrass	*Panicum virgatum* L.	Blackwell	Oklahoma	USDA-SCS, Manhattan, KS
Big bluestem	*Andropogon gerardi* Vitman	Niagara	New York	USDA-SCS, Big Flats, NY
		Champ	Nebraska	Univ. Nebr., Lincoln, NE
Sand bluestem	*Andropogon hallii* Hack.	Goldstrike	Nebraska	Univ. Nebr., Lincoln, NE
Little bluestem	*Schizachyrium scoparium* (Michx.) Nash	Aldous	Kansas	USDA-SCS, Manhattan, KS
		Cimarron	Kansas	USDA-SCS, Manhattan, KS
Sand lovegrass	*Eragrostis trichodes* (Nutt.) Wood	NE-27	Nebraska	Univ. Nebr., Lincoln, NE
Indiangrass	*Sorghastrum nutans* (L.) Nash	Holt	Nebraska	Univ. Nebr., Lincoln, NE
		NE-54	Nebraska	Univ. Nebr., Lincoln, NE
		Oto	Nebraska	Univ. Nebr., Lincoln, NE
Sideoats grama	*Bouteloua curtipendula* (Michx.) Torr.	El Reno	Oklahoma	USDA-SCS, Manhattan, KS
		Trailway	Nebraska	Univ. Nebr., Lincoln, NE
Deertongue	*Dichanthelium clandestinum* (L.) Gould	Tioga	Pennsylvania	USDA-SCS, Big Flats, NY

Table 3.—Seeding rates (lb/acre), species and cultivars used in eight mixtures sown in New Hampshire, Vermont, and New York during 1984-1987.

Location/Year	Switchgrass	Big Bluestem	Little Bluestem	Sand Bluestem	Sand Lovegrass	Deertongue	Indiangrass	Birdsfoot Trefoil	Hairy Vetch	Flatpea	Perennial pea
Franklin Falls,NH 1984	Blackwell 4.0	Niagara 6.0	Aldous 6.0	-	-	-	NE-54 6.0	-	-	-	-
Bennington,VT 1985	Blackwell 6.0	Niagara 4.0	Aldous 2.0	-	-	-	-	-	-	-	-
Alton,NH 1984	Blackwell 2.0	Niagara 3.0	Aldous 3.0	-	-	Tioga 1.0	NE-54 3.0	Viking 2.0	-	-	-
S.Woodbury,VT 1985	Blackwell 6.0	Niagara 3.0	Cimmaron 2.5	-	-	-	-	-	-	-	-
Bennington,VT 1987	Blackwell 3.0	Niagara 2.0	Aldous 2.0	Goldstrike 1.0	NE-27 1.5	-	KY-591 2.0	Viking 1.5	Common 3.0	Lathco 3.0	Lancer 3.0
Watson,NY 1987	Blackwell 3.0	Niagara 2.0	-	Goldstrike 1.0	NE-27 1.5	-	KY-591 2.0	Viking 1.5	Common 2.0	Lathco 2.0	-
Speculator,NY 1987	Blackwell 3.0	Niagara 2.0	-	Goldstrike 1.0	NE-27 1.5	-	KY-591 2.0	Viking 1.5	Common 2.0	Lathco 2.0	-
Concord,NH 1987	Blackwell 4.0	Niagara 4.0	Aldous 2.0	Goldstrike 2.0	NE-27 2.0	-	NE-54 2.0	-	-	-	

The test site was limed at 1 ton/acre, fertilized with 0-25-25 at 478 lb/acre, hand seeded, hand raked, and mulched with straw at a rate of 1,500 lb/acre.

The Ossipee site is located on a log storage area at the S.D. Warren facility. It was forested until 1983 when it was stripped of timber, topsoil, and most subsoil, then used to store logs through 1984. The soil material consists of sands more than 5 ft deep, with bark residue on the surface. The seasonal high water table is between 3-6 ft below the ground surface.

Thirty, 12.5-ft by 25-ft plots were limed at 1,000 lb/acre, fertilized with 320 lb/acre of 0-10-40, hand seeded, and hand raked. The residual bark raked in with the seed, lime, and fertilizer negated the need for mulch. The area was seeded on May 29, 1985. It was top dressed with urea fertilizer in June of 1987.

Franklin Falls, NH, Large Plots

'Blackwell' switchgrass, 'Niagara' big bluestem, 'NE-54' indiangrass, and 'Aldous' little bluestem (table 3) were planted with a no-till drill. Each species was planted separately in two randomly assigned strips 13-ft by 300-ft in size with an 8-in row spacing. Phosphorus (P_2O_5) and potassium (K_2O) were both banded at 25 lb/acre with minimal incorporation; lime was spread at 2 tons/acre. Problems with the feeding of the indiangrass and little bluestem seed through the drill resulted in uneven seed distribution. The switchgrass and de-bearded big bluestem planted acceptably at about 2 inches deep. The plantings were mulched for 2/3 of the strip length with rye straw, but most of it blew off the plot area.

Bennington, Vt, 1985 Planting

A depleted section of an active gravel mine was selected for this planting. The site has two different surface conditions; the uphill half has a coarser texture with larger stones while the remainder has smaller stones and more sand-sized material. The aspect is east.

A mixture of 'Blackwell' switchgrass, 'Niagara' big bluestem, and 'Aldous' little bluestem (table 3) was broadcast seeded and tracked. Tracking amounted to running a bulldozer back and forth over the site, overlapping the tracks so that the area was completely covered. Tracking was less effective in scoring the surface of the ground on the uphill part of the site. Fertilizer was applied at 24 lb/acre each of N,P_2O_5, and K_2O; the N source was ammonium nitrate. The planting was not mulched.

Alton, NH, Hydroseeding

This site was a cut sand bank which had been bare for several years, with active sloughing occurring in places due to foot traffic and washing from heavy rain. 'Niagara' big bluestem, 'Blackwell' switchgrass, 'NE-54' indiangrass, 'Aldous' little bluestem, and 'Tioga' deertongue, along with 'Viking' birdsfoot trefoil were hydroseeded with 800 lb/acre of 8-16-16 fertilizer and 4,000 lb/acre of lime. No methods of incorporation were used, but the bank was mulched with hay and tackified. Within a week of planting a very intense rain caused extensive sand movement in spite of the mulch.

South Woodbury, VT, 1985 Planting

A site in South Woodbury at 1,150 ft above sea level had been used as a sand and gravel pit for years. By 1984, the sand and gravel resources were exhausted in two areas of the pit. The same soil material existed at each of the 1.5 acre sites, but one site had a northern exposure while the other had a southern exposure.

Both sites were seeded on June 5, 1985. Prior to seeding, the owner smoothed and graded the sites with a bulldozer, leaving the banks at a slope of 25%. A hand broadcast mix of 'Blackwell' switchgrass, 'Niagara' big bluestem, and 'Cimarron' little bluestem (table 3) was applied at the rate of 8 lbs/acre. Fertilizer was applied at both sites as 0-20-20 at the rate of 400 lb/acre. A hay mulch was spread over the northerly exposed site only, at the rate of 1,000 lb/acre. After the materials were spread, the owner 'tracked' each site with a bulldozer to incorporate the seed and to anchor the mulch.

Bennington, VT; Watson and Speculator, NY, 1987 Plantings

These plantings were made to evaluate long-term cover under low maintenance. Legumes were added to the basic C_4 grass mix to provide a nitrogen source (table 3). A level 1-acre site near Bennington, which had been mined until 1972, was selected for planting. It was devoid of vegetation. After 480 lb/acre of 6-24-24 fertilizer was applied, the seed was broadcast and the entire site was tracked with a bulldozer. The Watson site was located in a town borrow pit. The surface material consisted of sand and fines with little gravel. The same conditions existed at the Speculator site, but instead of a flat area, part of the seeding went on sideslopes of the pit.

The legumes were added to the grass mix as single species in 25-ft wide strips across the planting site. One winter annual (hairy vetch) and 3 perennials ('Lathco' flatpea, 'Lancer' perennial pea, and 'Viking' birdsfoot trefoil) were used. See table 3 for details regarding species, cultivars and seeding rates.

Concord, NH, Fertility Trial

At Concord, a sandy, droughty slope was planted to a C_4 mixture of 'Blackwell' switchgrass, 'Niagara' big bluestem, 'Garden' sand bluestem, 'Aldous' little bluestem, 'NE-27' sand lovegrass, and 'NE-54' indiangrass. Five fertility treatments were replicated twice. They are detailed in table 4. After hand raking, the entire site was mulched with 2,100 lb/acre of straw.

Table 4.--Fertility treatments at Rt. 106, Concord, NH

Treatment No.	Urea	NH_4NO_3	IBDU[a]	P_2O_5	K_2O	$CACO_3$
	lb/acre					
1	75	--	--	62	62	2090
2	31	--	36	62	104	2090
3	15	57	--	62	62	2090
4	15	--	--	62	62	2090
5	41	--	61	62	132	2090

[a] Water insoluble N source, isobutylidene diurea.

RESULTS AND DISCUSSION

Franklin Falls and Ossipee, NH, Small Plots

The tests of C_4 grasses were conducted to identify species and cultivars which might be as effective as 'Blackwell' switchgrass and 'Niagara' big bluestem. The trials were by no means exhaustive. Many other C_4 grass cultivars should be tested.

At the Ossipee plots, there was organic matter (bark) present on the surface, and the plants responded with good growth. At Franklin Falls, two problems affected the perimeter plots. Competing trees (white pine and birch), though very sparse and stunted, were not removed far enough away from the plots. Grass growth on the closest plots was reduced. Also off-road recreational vehicles damaged some plots. Plants on the remaining plots developed slowly until fertilized with urea in 1986.

Although more testing is needed, two previously untried species, sand bluestem and sand lovegrass, show considerable promise (table 5). These two species have performed very well despite fears that they would not be winterhardy or would succumb to leaf diseases. The performance of sand lovegrass is of special interest because the species has tiny seeds - a potential advantage where seed is to be broadcast and incorporation will be incomplete. 'Blackwell' switchgrass, 'Niagara' big bluestem, and 'Aldous' little bluestem have also provided good to excellent cover.

Table 5.--Performance of C_4 Cultivars at Ossipee and Franklin Falls, NH, Percent Cover. Average of 2 replications.

		Ossipee			Franklin Falls			
Species	Cultivar	1985	1986[a]	1987[a]	1985	1986[a]	1987[a]	1987 Aver.
Switchgrass	Blackwell[b]	35	70	80	19	60	80	80
Big bluestem	Niagara[b]	36	70	80	6	50	70	75
	Champ	22	50	50	6	20	30	40
Sand bluestem	Goldstrike	20	60	70	20	60	70	70
Little bluestem	Aldous	22	70	80	20	60	80	80
	Cimarron	25	80	90	1	10	30	60
Sand lovegrass	NE-27	60	70	85	43	80	80	82
Indiangrass	Holt	20	40	50	3	20	50	50
	NE-54	27	50	70	8	30	45	57
	Oto	12	30	40	10	40	50	45
Sideoats Grama	El Reno	20	50	60	8	20	30	45
	Trailway	15	35	50	1	10	20	35
Deertongue	Tioga	5	10	30	1	5	10	20
Control Plots		0	10[c]	15[c]	0	0	0	8[c]

[a] Estimates made from photo documentation.
[b] Blackwell and Niagara, 4 reps at each location.
[c] Blackberries, herbaceous weeds.

Indiangrass and deertongue have been a disappointment on these droughty sites. Both species have been slow to establish and have had poor vigor. The relatively poor performance of deertongue is especially noticeable because the species does volunteer readily on droughty sites throughout the Northeast.

Cultivars with inconsistent performance between replications included 'El Reno' sideoats grama, 'Cimarron' little bluestem, 'Holt', 'Oto' and 'NE-54' indiangrass, 'Champ' big bluestem and 'Tioga' deertongue.

Franklin Falls, NH, Large Plots

This discussion will focus on results with 'Blackwell' switchgrass and 'Niagara' big bluestem. As noted earlier, planting problems with little bluestem and indiangrass greatly affected the performance of those species.

Populations of 'Blackwell' and 'Niagara' exceeding 12 seedlings/ft of row, developed in 1985 and have remained through 1987. Where mulch did not blow off, the seedlings appeared to develop more slowly than in unmulched areas. Until the plots were top-dressed with 80 lb/acre of urea in 1986, both cultivars grew slowly. By October of 1987 the 'Blackwell' and 'Niagara' had leaf canopy heights of 36 and 30 inches respectively.

Bennington, VT, 1985 Planting

Seedlings of three species (switchgrass, big and little bluestem) developed rapidly. At the end of 1986 the mixture was providing 60 percent cover on the lower half of the site, where there were fewer stones. In the upper section with heavy surface stones, the cover estimate was 40 percent.

Alton, NH, Hydroseeding

Switchgrass, big bluestem, and little bluestem have established very effective cover on the lower half of the sand bank. The upper half was washed severely by heavy rain just after the planting was completed in 1984, however the cover is improving steadily. Individual switchgrass plant bases have spread to 8 inches in diameter, and new seedlings are emerging each year. Deertongue and birdsfoot trefoil have established only at the base of the slope. Only a few indiangrass plants have established, but they have vigor equal to the big bluestem.

South Woodbury, VT, 1985 Planting

The mixture of switchgrass, big bluestem, and little bluestem produced markedly different growth and cover on the north vs. south facing slopes. The north slope had a 40 percent cover (predominantly switchgrass)in 1986, but has not improved significantly since. The owner began using the center of the plot for a roadway to the top of the slope in 1987, so future improvement may be unlikely.

The south slope has had exceptional cover since the summer of 1986. About 50 percent cover was achieved in 1985, 70 percent in 1986, and 85 percent was the estimate by the end of 1987. All three species are strongly represented, but big bluestem and switchgrass provide most of the cover.

Bennington, VT, Watson and Speculator, NY, 1987 Plantings

First year data on establishment have been recorded for these three test sites. The C_4 grass mix has established at all sites in sufficient numbers to achieve acceptable cover in 1988. The establishment of legumes varied among the three sites. At Bennington, 'Lathco' flatpea had the most seedlings present, followed by hairy vetch, with few birdsfoot trefoil seedlings (less than 1/per yd^2. The Speculator planting had good establishment of the trefoil and hairy vetch, but the flatpea was present at less than 1/yd^2. The Watson site had exceptional growth from the hairy vetch; it may crowd out the C_4 grasses in 1988. Trefoil and flatpea plant populations were low at 1-2/yd^2.

Concord, NH, Fertility Trial

The purpose of this study is to determine if a slow-release nitrogen source, isobutylidene diurea (IBDU), would encourage plant growth and establishment of C_4 grass seedlings during the seeding year. After one growing season, seedlings of 'Blackwell' switchgrass and 'NE-27' sand lovegrass are 3 to 4 times more numerous than the other species planted. Treatments 2,3, and 5 contain seedlings which are 3-4 inches taller and a darker green than those in treatments 1 and 4 (table 4). Treatment 2 utilized IBDU for 54 percent of the total N complement, while treatment 5 had 60 percent of the N as IBDU. Treatment 3 had no IBDU, but did have 79 percent of the N as ammonium nitrate.

Treatments 2 and 5 appeared to result in slightly better growth than treatment 3. The green color of the plants in treatments 2, 3, and 5 in October has caused concern about winterkill. Future observation will be needed to determine any lasting effects.

SUMMARY AND CONCLUSIONS

The small plot work has helped to identify two species and cultivars that may be worthy of inclusion in warm-season grass mixtures for sand and gravel mine revegetation in the Northeast. 'Goldstrike' sand bluestem and 'NE-27' sand lovegrass have been impressive at two locations in New Hampshire. In mixtures, they should be added to 'Blackwell' switchgrass, 'Niagara' big bluestem, and 'Aldous' little bluestem for the most rapid, effective cover tested to date.

For even seed distribution and proper placement a no-till drill provided the best results. Broadcast seedings have been successful where the seed and fertilizer were tracked into the surface with a bulldozer. The technique was not beneficial where large surface rocks prohibited penetration by the track cleats. Hydroseeding was moderately successful at one test site.

In northern Vermont, warm-season grasses grew far more vigorously on a slope with southern exposure than on a north-facing slope. This differential response suggests that there may be sites which cannot be successfully vegetated with C_4 grasses due to microclimatic factors in northern New England and New York.

One seeding which included hairy vetch with warm-season grasses had improved first year cover compared to the grasses used alone. However, the second and third year impacts need to be evaluated before this practice can be recommended.

A warm-season grass mixture fertilized with a slow-release nitrogen source exhibited better first year growth than the same mixture treated with urea. Slow-release nitrogen fertilizers should be used in future trials to find ways of establishing C_4 grass cover quickly on droughty sites.

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SOIL FUNGAL COMMUNITY-PLANT RHIZOSPHERE INTERACTIONS DURING THE EARLY STAGES OF ECOSYSTEM DEVELOPMENT ON RECLAIMED COAL MINE SOILS[1]

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Abstract.--The reestablishment of microbial populations in the rhizosphere of plants growing on reclaimed coal mine soils is imperative to help accelerate revegetation by enhancing biological activity and nutrient cycling processes. In the present study, the microfungal community was evaluated in the rhizosphere and nonrhizosphere zones of galleta (Hilaria jamesii), alkali sacaton (Sporobolus airoides), and fourwing saltbush (Atriplex canescens) growing on a reclaimed coal mine soil after 0.25, 1.25, and 2.25 years of plant growth. Of the three plant species, the rhizosphere of fourwing saltbush had significantly higher fungal populations than the rhizosphere of galleta or alkali sacaton 2.25 years after plant establishment. Although, the diversity of fungal groups in the rhizosphere and nonrhizosphere zones of all three plant species generally increased with plant age, the diversity of fungal groups in the rhizosphere of all three plant species were still lower than in the nonrhizosphere soil. Higher fungal populations and lower fungal diversities were generally related to higher nutrient contents in the rhizosphere, whereas lower fungal populations and higher fungal diversities were generally related to lower nutrient contents in the nonrhizosphere soil. Fungal groups changed between rhizosphere and nonrhizosphere zones, and among and within plant species as the age of the plants increased. Chrysosporium spp. dominated the rhizosphere and nonrhizosphere of all three plant species after 0.25 years. After 2.25 years, Aspergillus spp. dominated the rhizosphere of both grass species, whereas Penicillium spp. dominated the rhizosphere of fourwing saltbush.

INTRODUCTION

Research that has involved the belowground ecosystem in reclaimed coal mine soils has shown that changes in microbial populations and in the types of microorganisms involved may affect patterns of nutrient cycling activities during ecosystem development in soils which were not specifically from the rhizosphere (Fresquez et al. 1986, Parker et al. 1986). The potential interactions between plant roots and their associated microflora have been found to be important in other studies. Reviews by Rovira and Davey (1974) and Whipps and Lynch (1986) have indicated that different plant species excrete different types and amounts of organic materials (exudates) that influences the microflora composition in the rhizosphere. In turn, the rhizosphere microbial community provides substantial amounts of nutrients for plant use and acts as a buffer allowing plants to cope with environmental stress. Also, the benefits of an active rhizosphere environment are not only due to an increase of nutrients to the plant, but to the excretion of growth regulators such as gibberellins, auxins, cytokinins and indolyl acedic acid (Russell 1973).

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The microbial community is often responsible for the modification of adverse soil properties (Alexander 1977). The reestablishment of microorganisms in the rhizosphere may be of particular importance in the revegetation and stabilization of mining spoils where the soil properties are unfavorable in the surrounding soil (away from the root) for microbial growth (Cundell 1977). The objective of this study was to determine the microfungal component and soil chemical properties in the rhizosphere and nonrhizosphere of native grass and shrub species growing in a reclaimed coal mine soil during the initial stages of plant community development.

MATERIALS AND METHODS

Rhizosphere and nonrhizosphere soil samples were collected from plots on which galleta (Hilaria jamesii), alkali sacaton (Sporobulus airoides) and fourwing saltbush (Atriplex canescens) were growing on a reclaimed coal mine soil 0.25, 1.25 and 2.25 years after initial plant establishment in July of 1982, 1983 and 1984, respectively. The disturbed area, reclaimed in 1982, was on the San Juan Coal Mine located 24 km west of Farmington, NM. This site was revegetated by grading and leveling the overburden spoil material, spreading stockpiled topsoil material 20 to 30 cm deep over the recontoured spoil, mulching with 4.5 metric tons of grass hay / ha crimped 15 cm deep, fertilizing with 72 kg N and 90 kg P/ ha, seeding with ten native plant species, and irrigating for two growing seasons (Fresquez et al. 1986).

At each sampling period, rhizosphere and nonrhizosphere samples for each plant species were collected randomly along each of four permanently located transects. Each replication of a plant species (4 replications per plant species) included sampling the rhizosphere (0 to 7 cm from the the stem of the plant), and nonrhizosphere (30 cm away from the stem of the plant). The rhizosphere was collected by carefully removing the plant(s), and placing the roots and clinging soil in a sterile plastic bag. The topgrowth was separated and placed in a separate bag, each time by removing the shootgrowth 6 mm above the crown of the plant. The nonrhizosphere soil samples were collected using a soil bucket auger (5 cm in diameter) to a depth of 13 cm. Both plant and soil samples were immediately cooled in an ice-chest for transport to the laboratory. At the laboratory, the rhizosphere soil samples were separated into soil and root material. All soil samples were passed through a 2-mm sieve. An aliquot from each sample was taken for chemical analysis at the New Mexico State University Soil and Water Testing Laboratory. All methods of analyses have been described previously (Fresquez and Lindemann 1983). Shootgrowth and rootgrowth were dried for 78 h at 60°C and weighed; root to shoot ratios (R:S) were determined from this data.

Rhizosphere fungal populations were estimated by methods similar to those described by Lochhead (1940) and Starkey (1958). Approximately 9 g of soil and the respective root system were placed in a preweighed 125-mL bottle containing 95-mL of sterile saline (0.85%) solution. For nonrhizosphere soil 10 g of soil was used. Dilutions were plated in triplicate on rose-bengal-streptomycin agar (Martin 1950), and incubated at 25°C in the dark for 7 days.

After diluting and plating, the roots were washed and removed. The wash water was collected in the original bottle and evaporated to dryness at 110°C. Both rhizosphere and nonrhizosphere soil samples were treated in this manner. The contents of the dilution bottles were weighed and the number of fungal propagules computed on a per gram of oven-dry material basis.

Variations in soil chemical properties and in the populations of fungi were analyzed using standard analysis of variance. Fungi were analyzed using natural log-transformed data. The Least Significant Difference (L.S.D.) test was used to compare soil chemical and fungal populations means at the 5% probability level.

Fungal groups were isolated by evenly distributing 1 mL of a 10^{-3} dilution from a 10-g oven-dry weight equivalent sample in a Petri dish, adding cooled rose-bengal-streptomycin agar, and swirling for an even distribution. Ten plates were inoculated for each composited (4 replications per composite) soil sample, and incubated at 24°C in the dark for 7 days. After incubation, a portion of every colony appearing on the rose-bengal-streptomycin plates was transferred to a carrot agar medium by removing a portion of the agar containing hyphal tips. The colony was subcultured on a carrot agar plate to allow for maximum fruiting potential and identification. After a 4-day incubation period the colonies were identified using the taxonomic guides of Barnett and Hunter (1972), Barron (1968), Gilman (1968) and Domsch et al. (1980).

The following three indices were employed to compare the distribution pattern for each of the fungal groups isolated. First was Shannon's index of species diversity (Zar 1974), which estimates community richness as:

$$H = \sum_{i=1}^{k} p_i \log p_i \qquad (1)$$

where p_i = the proportion of group i in the sample, and k = the number of groups. The corresponding test for evenness is:

$$J = H/H_{max} \qquad (2)$$

where H_{max} = the maximum possible diversity.

An estimate of the similarity in the fungal composition among the sample populations was calculated with Sorensen's presence community coefficient (SPCC), which was described by Mueller-Dombois and Ellenberg (1974) as:

$$SPCC = 200C/A+B \qquad (3)$$

where C is the total number of groups common to two samples, A is the total number of groups in Sample A, and B is the total number of groups in Sample B. If the same groups were found in both samples, then the community coefficient would be 100, whereas if they had no groups in common, the coefficient would be 0.

RESULTS AND DISCUSSION

Galleta (Hija) and alkali sacaton (Spai) had significantly higher R:S ratios (0.27 and 0.36) than to fourwing saltbush (Atca) (0.03) after only 0.25 years of plant growth. After 2.25 years of plant growth, however, fourwing saltbush had a significantly higher R:S ratio (0.15) compared to galleta (0.06) or alkali sacaton (0.06).

In general, most soil properties in the rhizosphere, and especially in the nonrhizosphere soil of galleta, alkali sacaton and fourwing saltbush significantly decreased with reclamation age (table 1). This decline probably reflects the depletion of the added fertilizer and hay amendments, decreased plant productivity after irrigation was terminated and a reduced nutrient cycle as succession advances.

With respect to the rhizosphere and nonrhizosphere zones after only 0.25 years of plant growth, soil NO_3-N, organic matter (OM), electrical conductivity (EC), and the sodium absorption ratio (SAR) were significantly lower in the rhizosphere of galleta and alkali sacaton compared to the nonrhizosphere soil. The rhizosphere of fourwing saltbush had significantly lower P and higher SAR compared to the nonrhizosphere. It was not until after 2.25 years of plant growth that many soil chemical properties were significantly higher in the rhizosphere of galleta, alkali sacaton and fourwing saltbush compared to the nonrhizosphere soil. For example, the rhizosphere of galleta had significantly higher P, NH_4-N, TKN, OM and EC than in the nonrhizosphere soil. Similarily, the rhizosphere of alkali sacaton had significantly higher P, NO_3-N, OM, EC and SAR than in the nonrhizosphere soil, whereas, EC and SAR in the rhizosphere of fourwing saltbush were significantly higher than

Table 1.--Selected chemical properties in the rhizosphere (R) and nonrhizosphere (NR) of galleta (Hija), alkali sacaton (Spai) and fourwing saltbush (Atca) growing on a reclaimed coal mine soil varying in age.

Plant species	Phosphorus and nitrogen				Organic			
	P	NH_4-N	NO_3-N	TKN	matter	EC	pH	SAR
	$\mu g\ g^{-1}$				$g\ kg^{-1}$	dSm^{-1}		
0.25-year-old								
Hija								
R	4.4 b[1]	1.0 b	4.5 b	464 b	9.8 d	3.7 b	7.9 a	10.6 b
NR	4.6 b	1.0 b	18.1 a	484 ab	11.4 c	6.8 a	7.6 c	14.9 a
Spai								
R	4.0 b	1.0 b	4.2 b	450 b	9.7 d	3.6 b	7.8 bc	10.2 b
NR	4.3 b	1.0 b	15.7 a	501 a	13.0 ab	6.7 a	7.8 bc	17.0 a
Atca								
R	3.5 c	1.0 b	5.2 b	430 bc	11.1 c	6.7 a	7.7 c	16.3 a
NR	4.1 b	1.2 ab	9.4 b	484 ab	10.1 d	6.4 a	7.8 bc	8.8 c
1.25-year-old								
Hija								
R	6.7	1.0	0.8	825	7.2	1.8	7.9	10.0
NR	3.5	0.5	1.3	335	7.8	5.0	7.8	11.3
Spai								
R	2.4	0.2	1.8	389	11.1	1.8	8.0	9.1
NR	1.8	0.9	1.3	361	9.5	3.4	7.8	8.0
Atca								
R	1.8	0.9	0.9	355	7.5	1.7	8.2	16.2
NR	4.1	1.2	1.4	402	10.8	3.7	8.0	14.5
2.25-year-old								
Hija								
R	4.5 b	1.4 a	1.1 c	502 a	14.1 a	1.6 c	7.9 ab	6.7 d
NR	3.5 c	0.7 bc	1.0 cd	362 c	12.1 bc	0.8 d	7.9 ab	6.4 d
Spai								
R	7.3 a	0.7 bc	1.3 c	402 c	10.8 cd	1.5 c	8.0 a	8.1 c
NR	2.9 cd	0.9 c	0.8 d	362 c	8.5 e	0.8 d	8.0 a	6.0 d
Atca								
R	2.4 d	0.7 bc	0.8 d	362 c	9.2 de	2.9 b	7.9 ab	10.6 b
NR	3.5 c	1.6 a	1.0 cd	428 bc	8.5 e	1.1 cd	8.0 a	9.5 c

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[1] Means within the same column followed by the same letter are not signifiantly different at the 0.05 level by the LSD test.

in the nonrhizosphere. Organic matter was the only other soil parameter that was generally higher in the rhizosphere of fourwing saltbush than in the nonrhizosphere, but the values were not significantly different, however. Soil P and especially OM in the rhizosphere of both galleta and alkali sacaton were significantly higher over those soil properties in the nonrhizosphere. The accumulation of many soil chemical properties, particularly P, are found to be higher in the rhizosphere in the presence of microorganisms compared to the nonrhizosphere (Bowen and Rivera 1966).

Populations of fungi in the rhizosphere and nonrhizosphere zones of galleta and alkali sacaton, and in the nonrhizosphere soil of fourwing saltbush generally decrease with reclamation age (table 2). Of the three plant species, the rhizosphere of fourwing saltbush had significantly higher fungal populations than the rhizosphere of galleta and alkali sacaton. Also, the significantly higher fungal populations and lower diversity of fungal groups in the rhizosphere of fourwing saltbush compared to the nonrhizosphere soil after 2.25 years of plant growth suggests a root environment highly conducive to fungal growth.

A significantly higher fungal population in the rhizosphere of fourwing saltbush compared to the nonrhizosphere cannot be attributed to the measured soil chemical properties alone, as EC and SAR were the only soil chemical properties that were significantly higher in the rhizosphere

Table 2.--Fungal propagules ($10^{-3}g^{-1}$) in the rhizosphere (R) and nonrhizosphere (NR) of galleta (Hija), alkali sacaton (Spai) and fourwing saltbush (Atca) growing on a reclaimed coal mine soil varying in age.

	Hija	Spai	Atca
0.25-year-old			
R	414 a A[1]	460 b A	360 c A
NR	110 b	91 c	82 d
1.25-year-old			
R	148 b C	879 a B	1929 b A
NR	42 c	24 d	27 d
2.25-year-old			
R	71 c B	91 c B	14339 a A
NR	13 d	10 d	28 d

[1] Means within the same column followed by the same lower case letter are not significantly different at the 5% probability level by the L.S.D. test. Similarly, means within the same horizontal row followed by the same upper class letter are not significantly different.

Table 3.--Fungal diversity (H) and evenness (J) in the rhizosphere (R) and nonrhizosphere (NR) of galleta (Hija), alkali sacaton (Spai) and fourwing saltbush (Atca) growing on a reclaimed coal mine soil varying in age.[1]

	Hija		Spai		Atca	
	H	J	H	J	H	J
0.25-year-old						
R	0.68	0.57	0.72	0.60	0.82	0.65
NR	0.79	0.69	0.75	0.61	0.93	0.74
1.24-year-old						
R	0.93	0.81	0.73	0.61	0.40	0.37
NR	0.78	0.62	0.68	0.63	1.01	0.79
2.25-year-old						
R	1.04	0.76	0.78	0.70	0.98	0.73
NR	1.14	0.85	1.15	0.82	1.15	0.83

[1] Diversity calculated from isolates occurring on ten 1:1000 soil dilution plates.

of fourwing saltbush compared to the nonrhizosphere. Also, the amount of OM in the rhizosphere of fourwing saltbush after 2.25 years of plant growth was generally lower than the OM in the rhizosphere of galleta or alkali sacaton. A comparison of R:S ratios, on theother hand, shows that fourwing saltbush after 2.25 years of plant growth had an R:S ratio 2.5 times higher than either galleta or alkali sacaton. The amount of C material released by plant roots may depend upon root weight (Wood 1987). However, Bamberg et al. (1973) have shown that the amount of fixed C translocated to the roots by shrub species, including fourwing saltbush was considerably lower than grass species. Thus, the stimulation of the fungal community in the rhizosphere of galleta or alkali sacaton may have been partially due to the amount of root biomass, which may have influenced the type rather than the amount of C released as exudates by fourwing saltbush.

The diversity and evenness of fungal groups in the rhizosphere and nonrhizosphere of galleta, alkali sacaton and fourwing saltbush generally increased with reclamation age (table 3). After 2.25 years of plant growth, however, the diversity of fungal groups in the rhizosphere of galleta, alkali sacaton and fourwing saltbush were generally lower compared to the diversity in the nonrhizosphere soil. Generally, higher fungal populations and lower fungal diversities are related to either adverse soil or surface conditions, or to soils high in nutrient levels (Guillemat and Montegut 1960, Joffe 1967, Dennis and Fresquez, unpublished data). In contrast, lower fungal populations and higher fungal diversities are associated with moderately low nutrient levels (Dennis and Fresquez, unpublished data). Thus, while the soil nutrient status was decreasing with reclamation age, the rhizosphere of galleta, alkali sacaton and fourwing saltbush provided a more conducive environment to the fungal community than in the nonrhizosphere where there were less available nutrients.

The overall composition of fungal groups changed between the rhizosphere and nonrhizosphere zones, and among and within plant species as the age of the plants increased in age. With respect to the composition of fungal groups between the rhizosphere and nonrhizosphere zones of galleta, alkali sacaton and fourwing saltbush, it was found that the percent similarity between these zones decreased as the age of galleta and alkali sacaton increase. In contrast, the similarity in the composition of fungal groups between the rhizosphere and nonrhizosphere of fourwing saltbush increased slightly from 72 to 78% with plant age. This suggested that the rhizosphere of fourwing saltbush may have influenced the types of fungal groups in the nonrhizosphere soil 2.25 years after plant establishment more than the rhizosphere of galleta or alkali sacaton. The rhizosphere of galleta, alkali sacaton and fourwing saltbush changed among plant species as the plants increased in age from 0.25 to 2.25 years. For example, the percent similarity (SPCC) between plant species after 0.25 years of plant growth was high ranging from 71 to 88%. After 2.25 years of plant growth, the percent similarity of fungal groups in the rhizosphere between plant species decreased, ranging from 61 to 67%. Also, an overall decrease in the percent similarity of fungal groups isolated in the rhizosphere within the same plant species occurred with age. As the plants increased in age from 0.25 to 2.25 years, the fungal composition in the rhizosphere of galleta decreased to 56%; alkali sacaton decreased to 55%; and fourwing saltbush decreased to 60%.

Different fungal groups dominated the rhizosphere and nonrhizosphere of galleta, alkali sacaton and fourwing saltbush as the plants increased from 0.25 to 2.25 in age (table 4). *Chrysosporium* spp. dominated the rhizosphere and nonrhizosphere of galleta, alkali sacaton and fourwing saltbush 0.25 years after plant establishment. After 2.25 years of plant growth, *Aspergillus* spp. dominated the rhizosphere of galleta and alkali sacaton, while *Penicillium* spp. dominated the rhizosphere of fourwing saltbush. *Penicillium* spp. accounted for 33% of the total isolates from the rhizosphere of fourwing saltbush and was probably the fungal group most responsible for the majority of the enumerated propagules in the rhizosphere of fourwing saltbush 2.25 years after plant establishment (table 4).

Table 4.--Major fungal groups in the rhizosphere (R) and nonrhizosphere (NR) of galleta (Hija), alkali sacaton (Spai) and fourwing saltbush (Atca) growing on a reclaimed coal mine soil varying in age. (% of total isolates).

	Hija	Spai	Atca
0.25-year-old			
R	Chrysosporium (43)	Chrysosporium (44)	Chrysosporium (40)
NR	Chrysosporium (44)	Chrysosporium (46)	Chrysosporium (33)
1.25-year-old			
R	Chaetomium (28)	Penicillium (60)	Myrothecium (77)
NR	Chaetomium (50)	Penicillium (25)	Chaetomium (14)
2.25-year-old			
R	Aspergillus (31)	Aspergillus (65)	Penicillium (33)
NR	Aspergillus (25)	Chaetomium (28)	Aspergillus (24)

CONCLUSIONS

These data show that an active rhizosphere environment may be a vital attribute to the overall success of revegetation on reclamined coal mine soils. Each plant species, however, may affect or contribute differently to the overall success of revegetation. Of the three plant species, the rhizosphere of the grass species had significantly higher N and P, and OM accumulation than the rhizosphere of fourwing saltbush. On the other hand, the rhizosphere of fourwing saltbush had significantly higher EC and SAR than the rhizosphere of the grass species 2.25 years after plant establishment. The rhizosphere of fourwing saltbush, however, was more conducive to fungal growth than galleta or alkali sacaton. As a result of this, the rhizosphere of fourwing saltbush may contribute to greater decomposition and soil aggregation processes more deeply into the soil profile than the rhizosphere of the two grass species. In contrast, the rhizosphere of galleta and alkali sacaton may contribute more to nutrient cycling processes, particularly N and P, and OM accumulation more near the soil surface than the rhizosphere region of fourwing saltbush.

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SELENIUM UPTAKE BY ALFALFA AND WHEAT GROWN ON A MINE SPOIL RECLAIMED WITH FLY ASH[1]

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Abstract.--A field experiment was conducted to determine the selenium uptake in crops grown on a mine spoil reclaimed with fly ash. Large amounts of selenium present in fly ashes could lead to accumulation of Se in plants grown on fly ash amended spoils at levels toxic to animals. Alfalfa and wheat grown on a mine spoil treated with fly ash contained sufficient, but nontoxic levels of Se for animal nutrition. Addition of rock phosphate to a fly ash-amended spoil decreased the Se content of alfalfa, but not of wheat. Phosphorus-induced reduction of Se content of alfalfa was not related to Se content of the soil solution, but possibly to the mechanisms operating on the root surfaces or within the plants. Low Se uptake from fly ash treated mine spoils appeared to result from the adsorption of Se on oxides of Fe and Al present in the fly ash and to the low pH of the mine spoil.

INTRODUCTION

Many abandoned mine lands in the Eastern U.S. are highly acidic due to the oxidation of pyrite or marcasite which occurs in overburden strata. When exposed to air and moisture following mining, pyrite oxidizes to produce H^+ and acid forming ions, such as, Fe^{2+}, Fe^{3+}, and SO_4^{2-}, which cause vegetation failure on the mine spoils (Arnon and Johnson 1942, Knabe 1964, Lundberg et al. 1977, and Kimber et al. 1978). At low pH various metals come into soil solution in toxic amounts, the most common being Al^{3+}, Mn^{2+}, and Fe^{2+}. To vegetate acid mine spoils requires an amendment which contains basic cations.

Fly ash is the material trapped by electrostatic precipitators in coal-burning electric power generating plants. Elemental composition of fly ash is quite variable, but several researchers (Cope 1962, Capp and Engle 1967, and Hodgson and Holliday 1966) have shown that it usually contains higher concentrations of basic cations and some essential plant nutrients except for N and P than soils. Several greenhouse studies (Martens and Beahm 1978, Martens et al. 1970, and Chang et al. 1977) have indicated that many chemical constituents of fly ash may benefit plant growth and improve agronomic properties of soils. Fly ash has been added as an alkaline amendment to coal mine spoils and refuse banks to permit their reclamation for plant growth (Capp and Engle 1967, Kovacic and Hardy 1972, Fail and Wochok 1977, Keefer et al. 1979, and Keefer and Singh 1985).

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The extremely low levels of P in fly ash applied to soils often result in P concentrations in plant tissue lower than control plants (Adriano et al. 1978, Martens 1971). Much of the P found in fly ash is unavailable for plant uptake (Mack and Knight 1985) due to the high alkalinity of fly ashes. The availability of P to plants is seriously reduced under highly alkaline conditions due to formation of insoluble calcium phosphates and other complexes (Townsend and Gillham 1975). Townsend and Hodgson (1973) reported substantial yield increases following fertilization of ash-grown plants with water-soluble phosphate. Ghazi (1984) reported that phosphate requirements of fly ash-amended mine spoils can be met by addition of rock phosphate.

Analysis of fly ashes (Davison et al. 1974, and Furr et al. 1976) revealed a number of essential elements; however, there were also some potentially toxic elements present. Fly ashes are generally high in oxyanion-forming trace elements, such as selenium, arsenic, boron, and molybdenum. Selenium is of particular concern because concentrations of Se in fly ash commonly exceed that typically found in soil and because Se is required at certain levels in animal nutrition, but becomes toxic somewhere between 2 mg/kg and 5 mg/kg.

Numerous investigators (Furr et al. 1976, Gutenmann et al. 1976, Straughan et al. 1978, and Furr et al. 1977) have shown that plants grown on pure fly ash and fly ash-treated soils contained higher concentrations of Se than those grown on untreated soils. In a literature review, Adriano et al. (1980) indicated that 11 references cited consistently showed an increase in Se uptake by plants grown on fly ash-treated soils, except for barley and trees. The high concentration of Se in fly ashes is of concern because, Se phytotoxicity is not observed at levels which would be toxic to animals; Se therefore could conceivably accumulate in the plants without any outward sign of phytotoxicity and result in excess Se getting in the food chain. Elements, such as Se, can contaminate the food chain at plant tissue concentrations lower than those that cause phytotoxicity and reduction in plant growth. Therefore, concentrations in plant tissue may have to be controlled by limits on land application of Se containing wastes (Logan et al. 1987). Selenium is one of the trace elements that is not protected by the so-called "soil-plant barrier" (Chaney 1983). Selenium accumulation in excess of 200 ppm has been reported for white sweet clover (*Melilotus alba*) grown on beds of fly ashes (Gutenmann et al. 1976). Most of these studies were conducted on plants growing on fly ash dumps or on agricultural soils receiving fly ash. Since no data are available showing Se accumulation by alfalfa or wheat grown on fly ash-amended mine spoils, the current study was designed to examine Se uptake under such conditions.

MATERIALS AND METHODS

Selenium uptake by alfalfa and wheat from mine spoils treated with fly ash and rock phosphate was investigated in conjunction with a study for revegetation of mine spoils using fly ash. The results of successful revegetation of these spoils with fly ash have been described elsewhere (Bhumbla et al. 1984). The fly ash used in this study was obtained from a coal fired power plant located in northern West Virginia (Fort Martin). Chemically, the fly ash used in this study was alkaline (pH 10.7) and contained 11 mg/kg of total Se (table 1). The rock phosphate, which was obtained from North Carolina, contained 10.5% phosphorus and 22.7% calcium.

Table 1.--Fly ash pH and total Chemical Analysis.

pH (1:1)	10.7
SiO_2	37.6 %
Al_2O_3	19.8 %
Fe_2O_3	28.9 %
CaO	6.2 %
MgO	1.0 %
SO_4^{2-}	1.5 %
K_2O	1.2 %
P_2O_5	0.4 %
Se	11.0 mg/kg

These experiments were conducted on an abandoned mine site, characterized physico-chemically (table 2), in Monongalia county, near Westover, WV. A field experiment was established in October 1982 with an experimental design of a randomized complete block in a factorial arrangement. The treatments consisted of 3 rates of fly ash, 0, 400, and 800 Mg/ha and 3 rates of rock phosphate, 0, 15, and 30 Mg/ha. The check in this experiment was a lime-superphosphate treatment in which lime and triple superphosphate were added at 22.5 Mg/ha and 300 kg/ha, respectively. The amendments were incorporated into the spoils by disking. There were five replicated plots for each treatment. These plots were seeded to a mixture of alfalfa (inoculated with the proper Rhizobium) and wheat. During the first year of crop production, wheat was sampled at jointing and at maturity; wheat plants at maturity were separated into grain and straw. Two cuttings of alfalfa were also harvested. Plant samples were washed with distilled water and dried at 65° C. in a forced air oven. The plant samples were ground in a Wiley mill to < 1 mm.

For P analysis, plant samples were digested according to the method of Ganje and Page (1974). For Se analysis, plant samples were digested with HNO_3. A 0.5-g

Table 2.--Physico-chemical properties of Westover mine spoil.

Physical Properties	
Particle size Analysis	
Sand	42.5 %
Silt	39.4 %
Clay	18.1 %
Texture	Loam
Chemical Properties	
pH	3.4
Organic Matter	2.10 %
Pyritic sulfur	0.35 %
CEC	9.95 cmol(+)/kg
Exchangable cations:	
Ca^{2+}	0.59 cmol(+)/kg
Mg^{2+}	1.27 cmol(+)/kg
K^+	0.14 cmol(+)/kg
Na^+	0.08 cmol(+)/kg
Al^{3+}	6.59 cmol(+)/kg
DTPA-extractable trace elements	
Zn^{2+}	6.9 mg/kg
Cu^{2+}	5.7 mg/kg
Mn^{2+}	60.1 mg/kg
Fe^{2+}	254.0 mg/kg
Total Se	18.2 mg/kg

sample of plant material was transferred to a 60-mL plastic bottle and 3 mL of doubly distilled nitric acid was added, allowed to digest overnight at room temperature, and further digested for 2 hours at 95° C. in a hot water bath. The final volume was adjusted to 10 mL with deionized distilled water. The solution was centrifuged at 6,000 g and the Se in the supernatant solution was measured with a graphite furnace using the method of Voth-Beach and Shrader (1987).

Selenium in the soil was extracted with 0.1 N $NaAsO_2$ according to the method of Cary et al. (1967). All other soil analyses were carried out using standard procedures from Page et al. (1982).

Data were analyzed statistically (ANOVA using SAS programs) with the computer at West Virginia University and L.S.D. values were computed at the 0.05 level of significance.

RESULTS AND DISCUSSION

Total analysis of fly ash shows that Se was present at a concentration of 11 mg/kg (table 1). The calculated total Se additions to the soil with fly ash application at 400 and 800 Mg/ha are 8.8 and 17.6 kg/ha (table 3). Although the total amounts of Se additions are not very large, Se additions as sodium selenate to agricultural soils at much lower rates have been reported to produce plants containing Se, at levels potentially toxic to animals. Singh and Singh (1978) reported > 5.0 mg/kg Se in plants grown on a soil treated with 2.5 mg/kg Se. In New Zealand, Se deficiency in forage plants was corrected by field application of Se at levels of Se of 70 g/ha (Grant 1965, Davies and Watkinson 1966). All investigators concluded that topdressing with 70 g of Se/ha as sodium selenite would be safe and would lead to an adequate Se level in the pasture. Thus, the additions of Se through fly ash in the present investigation were high enough to produce plants with hazardous levels of Se. However, several investigators (Gissel-Nielsen 1974, Dhillon 1972, and Singh and Singh 1978) have shown that Se uptake depends on several factors which include plant species, chemical form of the Se, soil type, and supply of other compounds such as sulfates and phosphates.

Table 3.--Selenium extracted by 0.1 M $NaAsO_2$ from a mine spoil amended with fly ash and rock phosphate.

Rate of Addition			
Fly ash	Rock Phosphate	Se from fly ash*	Extractable Se **in treated spoil**
----(Mg/ha)----		(kg/ha)	(ug/kg)
0	0	0	24.5
0	15	0	20.7
0	30	0	26.4
400	0	8.8	477.1
400	15	8.8	439.7
400	30	8.8	467.2
800	0	17.6	631.5
800	15	17.6	650.1
800	30	17.6	620.7
LSD (0.05)			53.2

*Calculated from amount of Se in fly ash.

The form in which Se is found in fly ashes is not known. It may be in the form of selenite (SeO_3^{2-}) or selenate (SeO_4^{2-}) since selenium oxides can be formed at the temperatures of over 800° C at which fly ashes are generated. A major fraction of Se in fly ash is likely to be adsorbed on oxides of Fe and Al since fly ash contains high amounts of Fe and Al (table 1). Phung et al. (1979) observed an increase in Se concentration with a decrease in particle size of fly ash, which implies a relationship between surface area of particles and Se concentrations.

Selenium concentrations in alfalfa plant tissue significantly increased with an increase in amount of fly ash applied (table 4). In both cuttings of alfalfa, the lowest Se concentrations were observed in plants growing on plots receiving no fly ash, and the highest amount of Se was found in plants growing in plots which were treated with the highest rate of fly ash (800 Mg/ha). The concentration of Se for two cuttings of alfalfa ranged between 0.05 and 1.24 mg/kg. Concentrations of Se above 5 mk/kg in animal diets are considered toxic (Thacker 1961, and Cary et al. 1967). Animal feeds of less than 0.1 mg/kg Se are related to occurrence of Se-responsive diseases in animals (Andrews et al. 1964). On this basis, it seems desirable to maintain the Se content of feed crops above 0.1 mg/kg and below 5 mg/kg. In the present investigation, Se content of alfalfa grown on mine spoil plots receiving no fly ash produced alfalfa which was deficient in Se for animal feed. Alfalfa produced on fly ash-treated plots contained Se in sufficient, but nontoxic levels. Low Se uptake in alfalfa grown on mine spoils having relatively high total Se content of 18.2 mg/kg is related to chemical properties of the mine spoil. In mine spoil with high acidity (low pH) containing high amounts of extractable Fe, Al, and Mn, Se was possibly precipitated as an insoluble Fe or Al selenite.

Various investigators (Dhillon 1972, Davies and Watkinson 1966, and Tripathi and Misra 1975) have reported an antagonistic relationship between Se and sulfate. The present mine spoil had a large amount of sulfate ions due to the oxidation of pyrite (table 1). These sulfate ions may have restricted the uptake of Se.

Selenium content of alfalfa grown on fly ash-treated soils decreased with increasing levels of rock phosphate additions. Significant reductions in Se content of alfalfa with rock phosphate additions were observed for both cuttings. In alfalfa grown on plots receiving 400 Mg/ha of fly ash, the Se content decreased from 1.10 mg/kg to 0.76 mg/kg with addition of 30 Mg/ha of rock phosphate. In plots receiving 800 Mg/ha of fly ash, this reduction in Se content with application of 30 Mg/ha of rock phosphate was from 1.24 mg/kg to 0.95 mg/kg. Similar antagonism between P and Se content of plants has been reported by Gissel-Nielsen (1971) and Singh and Singh (1978). This phosphate-induced reduction in Se uptake is not related to the concentration of Se in soil solution, but to the plant mechanisms responsible for uptake of these ions. This is supported by the data on extractable Se (table 3). Extractable Se increased significantly with increase in fly ash application, but rock phosphate additions had no effect on the amount of Se extracted. Thus, phosphate-induced reduction in uptake of Se by alfalfa is controlled by mechanisms operating at root surfaces or within the plant.

Table 4.--Plant tissue selenium content of alfalfa grown on mine spoil treated with fly ash rock phosphate mixtures.

Rate Added		Se in alfalfa	
Fly	Rock	Cutting	
Ash	P	1st	2nd
-(Mg/ha)--		--------(mg/kg)---------	
0	0	0.063	0.067
0	15	0.057	0.051
0	30	0.059	0.055
400	0	1.095	1.071
400	15	0.972	0.982
400	30	0.764	0.773
800	0	1.243	1.197
800	15	1.037	1.084
800	30	0.954	0.932
LSD (0.05)		0.057	0.063

Selenium concentration of wheat grown on fly ash-treated mine spoil increased with ash application (table 5). However, no differences in Se content of wheat were observed among the plots receiving fly ash. The highest Se concentration of 1.88 mg/kg was observed in young wheat plants growing on plots receiving 400 Mg/ha of fly ash. No significant differences in Se content of wheat plants were observed due to application of rock phosphate. This contrasting behavior for Se uptake between alfalfa and wheat is probably related to physiological differences between these two crop species and complex interaction betweeen P and Se uptake. Alfalfa is a dicotyledenous plant. Dicot plants have a high root cation exchange capacity, high Ca requirement, and release more acidity in the rhizosphere (Nyatsanga and Pierre, 1973). This increased acidity in the rhizosphere helped the dissolution of rock phosphate in fly ash-treated mine spoils, and thus resulted in increased uptake of P (table 6). In contrast, wheat is a monocotyledenous plant and has less capacity to generate acidity in its rhizosphere. Thus, it could not solubilize excess phosphate (table 7) for reduction of Se uptake. Gissel-Nielsen (1974) observed decreased Se in barley only when high levels of N were present. In the present study the same amount of N was added to wheat and alfalfa. However, alfalfa is a legume which has the capacity to fix atmospheric N. Thus, elevated levels of plant N in alfalfa may have helped the exclusion of Se from the plant due to the antagonism between Se and P in plants with high N content.

Selenium concentration in wheat grain produced on fly ash-treated mine spoils was much lower than the Se content of the straw (table 5). Thus, in the wheat crop

Table 5.--Selenium content of wheat tissue grown on a mine spoil treated with fly ash and rock phosphate mixtures.

Rate Added		Se in wheat		
Fly Ash	Rock P	Grain	Straw	Young Plant
-(Mg/ha)--		----------(mg/kg)----------		
0	0	0.024	0.029	0.030
0	15	0.020	0.031	0.027
0	30	0.030	0.023	0.029
400	0	0.793	1.645	1.858
400	15	0.784	1.588	1.821
400	30	0.779	1.675	1.878
800	0	0.789	1.678	1.869
800	15	0.757	1.599	1.823
800	30	0.769	1.635	1.854
LSD (0.05)		0.071	0.123	0.085

Table 6.--Phosphorus concentration of alfalfa grown on mine spoil treated with fly ash-rock phosphate mixtures.

Rate Added		P in plant tissue	
		Cutting	
Fly Ash	Rock P	1st	2nd
-(Mg/ha)--		--------(%)----------	
0	0	0.34	0.24
0	15	0.30	0.30
0	30	0.34	0.30
400	0	0.27	0.20
400	15	0.29	0.27
400	30	0.32	0.29
800	0	0.24	0.19
800	15	0.27	0.27
800	30	0.28	0.29
LSD (0.05)		0.02	0.01

grown on fly ash-amended mine spoil, the potential for Se toxicity is even less than that for alfalfa. Selenium concentrations in the edible portion, i.e., grain, was less than one-half of that found in the straw.

Table 7.--Phosphorus concentration of wheat tissue grown on mine spoil treated with fly ash-rock phosphate mixture.

Rate Added		P in plant tissue		
Fly Ash	Rock P	Young Plant	Straw	Grain
-(Mg/ha)--		------------(%)------------		
0	0	0.36	0.23	0.33
0	15	0.35	0.26	0.33
0	30	0.39	0.27	0.35
400	0	0.28	0.19	0.26
400	15	0.27	0.20	0.28
400	30	0.29	0.22	0.27
800	0	0.24	0.18	0.24
800	15	0.23	0.19	0.22
800	30	0.21	0.18	0.21
LSD (0.05)		0.05	0.04	0.05

Nontoxic concentrations of Se in plants grown on fly ash-amended mine spoil, even when 17.6 kg/ha of Se were added, are related to the favorable chemical properties of mine spoil and the presence of iron oxides in fly ash. Iron oxides adsorb Se only below a pH of 7.5 (Parks and deBruyn, 1962). In fly ash-treated mine spoils, the pH was lower than 7.0, which facilitated the adsorption of Se to oxide surfaces. Oxides of Fe possess a positive charge at pH values below their zero point of charge. When fly ash is added to mine spoils, the pH generally is maintained below 7.0 which is lower than the zero point of charge of Fe oxide. Thus, with regard to Se fly ash is probably safe to add to mine spoils.

CONCLUSION

Application of fly ash to a mine spoil increased the Se content of both alfalfa and wheat. The Se values were in the safe range between deficient and toxic, however those plots which did not receive fly ash contained insufficient Se for adequate animal nutrition. Application of rock phosphate along with fly ash decreased Se content of alfalfa, but not of wheat. Phosphorus-induced reduction in Se content of alfalfa was not related to the extractable Se content of soils, but to the mechanisms operating on the root surface or within the plant. The differences in Se uptake behavior of alfalfa and wheat grown on mine spoils amended with fly ash and rock phosphate were related to physiological differences between these two crops. Low Se uptake from fly ash-treated mine spoils appears to be related to the presence of oxides of Fe and Al in the fly ash. These oxides at pH below their zero point of charge are positively charged. Selenium is retained on these positively charged surfaces, and thus Se availability to plants is reduced. The results of this study demonstrate that alfalfa and wheat grown on fly ash-amended mine spoils contained sufficient, but non toxic amounts of Se.

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RECLAMATION OF SITE NEAR A SMELTER USING SLUDGE/FLY ASH AMENDMENTS: HERBACEOUS SPECIES[1]

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Abstract.--Emissions from two zinc smelters in Carbon County, PA, over an 80-year period caused the defoliation of nearby Blue Mountain. High levels of SO_2 slowly killed off the existing oak-chestnut forest and particulate metals built to very high levels in the soil. Current metals levels in the soil are as high as 1,300 ppm Cd; 6,474 ppm Pb; and 32,085 ppm Zn. These high levels have stopped microbial activity, and there has been no decomposition or regeneration for decades. The site is now on the EPA Superfund clean-up list. Both physical and chemical problems with the eroded soil need to be addressed to reclaim this site. The hypothesis tested was to use mixtures of sludge and fly ash, lime and potash to revegetate the site using metals-tolerant ecotypes of herbaceous species. Three ratios of sludge: fly ash were used (1:1, 2:1, and 3:1) on a volume basis. The sludge amount was a constant, based on the desired loading rate of N (2,100 kg/ha). The amendments were blown onto the site and not incorporated. Species used were 1) switchgrass, Panicum virgatum, 2) big bluestem, Andropogon gerardi, 3) tall fescue, Festuca arundinacea, plus birdsfoot trefoil, Lotus corniculatus, 4) flatpea, Lathyrus sylvestris, plus perennial ryegrass, Lolium perenne, and 5) intermediate wheatgrass, Elytrigia intermedia. Results in 1986 and 1987 were excellent with the 1:1 ratio being slightly superior across all species. This new reclamation technology may be applicable to a number of drastically disturbed areas.

INTRODUCTION

Zinc smelting has taken place in Palmerton, Carbon County, PA, since 1898. Two smelters, the second beginning operation in 1912, located at the base of Blue Mountain, operated continuously until 1980, when primary zinc smelting was terminated. Emissions from the smelters, both from the coal-fired physical plant and from the roasting, sintering, and smelting of zinc sulfide ores contributed to the defoliation of several thousand acres of adjacent land (Buchauer 1971, Jordan 1975).

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During the years of active smelting, very high levels of SO_2 were emitted into the atmosphere. In 1962, SO_2 emissions varied between 3,300 and 3,600 lb/hr, and it has been assumed that this rate had been essentially the same since 1918, since there had been no major process changes (PADER 1987). By 1970, SO_2 emissions had declined to an average of 1,400 lb/hr(Buchauer 1971). Particulates of cadmium, lead and zinc were also emitted, which built up in the soil at extreme levels. Historic estimates of total metals emitted are: cadmium - 3,740 tons or 47 tons/year; lead - 7,560 tons or 95 tons/year; and zinc - 286,000 tons or 3,575 tons/year (USEPA 1987).

In addition to the pollutants being emitted from the smelters, Blue Mountain has a history of burns and logging. By the time the original forest was killed by the SO_2, there were high enough levels of Cd, Pb, and Zn in the soil to prevent regeneration. Metals levels are so high that microbial activity has ceased, and trees that have been dead for 20 or more years cannot decompose.

Typical soil concentrations of zinc range from 10 to 300 ppm (Brady 1974), while concentrations measured on Blue Mountain varied between 26,000 ppm (Strojan 1978) to 80,000 ppm (Jordan 1975). Typical soil concentrations of cadmium range from 0.1 to 7.0 ppm (Brady 1974), and concentrations measured on Blue Mountain range from 900 ppm (Strojan 1978) to 1,500 ppm (Jordan 1975). Lead has been reported in concentrations as high as 6,474 ppm (Sopper and Oyler 1985).

Following the death of the forest, severe soil erosion occurred, and to date it appears that between 12 and 24 inches of topsoil have been removed from the site. As the soil eroded, rock layers emerged, slowing further movement. The metals levels in the upper 6 to 8 inches of soil remain at toxic levels, however.

In 1982, the U.S. Environmental Protection Agency placed this site on the National Priorities List (Superfund) for toxic site clean-up. Numerous remedial alternatives were evaluated, including removal of the top 12 inches of contaminated soil. Removal cost , without revegetation, was estimated at $1.3 billion (USEPA 1987). In addition to the contaminated soils on the mountain, there are approximately 33,000,000 yds^3 of metal-laden smelting residues in a bank 2-1/2 mi. long at the base of the mountain. Removal cost estimates for the cinder bank range from $1.5 to $2.8 billion, and could take from 29 to 45 years to complete, assuming there would be a place to dispose of it. Because of the unreasonably high environmental and economic costs associated with removal, it was decided to attempt to stabilize the metals on-site through proper pH management and revegetation.

There are many similar problems associated with smelter emissions in the United States and abroad. Gale and Wixson (1979), Wixson and Bennett (1975), Jackson and Watson (1977), Jennett et al. (1977), Jennett and Foil (1979), Kearney et al. (1981), and Bolter et al. (1975) all report very similar problems with zinc and cadmium pollution associated with lead and zinc smelting operations in and around Iron County, MO. Walsh and Bissell (1979) report sulfur dioxide and heavy metal damage to the forests in the vicinity of a copper smelter near Anaconda, MT. In the vicinity of a smelter in Kellogg, ID, Ragaini et al. (1977), Hansen and Mitchell (1978), and Carter and Loewenstein (1978), all report great quantities of SO_2, Zn, Cd, and Pb having been emitted during the smelting process, thus causing total destruction of nearby vegetation.

PAST REVEGETATION ATTEMPTS

Numerous attempts have been made to establish vegetation, both herbaceous and woody, on the contaminated soils of Blue Mountain, and at most of the other similar sites (Buchauer 1971, 1973, Jordan 1975, Soil Conservation Service 1977, 1978, 1979, 1980-81, 1982, 1983, Goodman et al. 1976, Goodman and Gemmell 1978, Hansen and Mitchell 1978.), and none were successful. These studies all demonstrated that conventional reclamation techniques were not capable of revegetating sites so drastically disturbed. Of the work done thus far on Blue Mountain, only two species of plants are surviving: 1) 'Merlin' red fescue, Festuca rubra, a proprietary cultivar from England that is priced far too high to be economical; and 2) common thrift, Armeria maritima, a species introduced from Norway that has limited conservation value and no commercial seed source, thus precluding large-scale use. Within the plots of the above listed species, even though the plants are surviving, there appears to be no significant insect or microbial activity, which raises doubts concerning long-term ecosystem stability.

Blauel and Hocking (1974), in concluding a multi-year study of the effects of air pollution and forest decline near a nickel smelter in Thompson, Manitoba, state that reclamation of land contaminated by smelter emissions would be an extremely complex and expensive proposition. The practical difficulty with reclamation is that errors in any of a number of steps in the operation can cause either temporary or permanent failure of the operation. Blauel and Hocking (1974) continue: "Besides sulfur, at Thompson the emissions include substantial amounts of arsenic, selenium, cadmium, lead, cobalt, nickel, copper, and zinc... The entry of these elements into the soil chemical and biological cycles constitutes initiation of major site degradation, because they cannot be 'neutralized' or removed easily. They could make extremely difficult or futile any reclamation attempts by currently known methods, and they would add substantially to the costs."

Goodman (1974) and Mills (1985) present the main environmental factors that inhibit or prevent growth of vegetation on waste materials from both the coal and metal industries. The conditions shown in table 1 apply to the Blue Mountain site.

Although most of these are physical problems, the research completed to date around smelter sites relates the failure to establish vegetation primarily to the excess of toxic metals in the soil. Most of the research previously cited has indicated that seedlings would emerge, but not survive past the 2- to 4-inch growth stage.

Table 1.--Conditions inhibiting or preventing revegetation of coal and metal industry wastes and projected solutions provided by innovative sludge/fly ash treatment.

Problem*	Solution
Physical:	
Eroded slopes	Revegetation
Very steep slopes	Spray
Inhibitory water regimes	Sludge, fly ash, mulch retain moisture
Compaction/cementation	Sludge/fly ash mix remains porous
Inhibitory surface temperatures	Light color of fly ash
Wind turbulence (sandblasting)	Sludge/fly ash mix remains stable
Absence of fine materials	Fly ash (soil-sized particles)
Broken, uneven surface	Spray on amendments
Chemical and Biological:	
High levels of toxic elements	Lime/fly ash
Macronutrient deficiency	Sludge (N+P), potash (K)
Micronutrient deficiency	Sludge/fly ash
Absence of soil microflora and fauna	Sludge

*From Goodman (1974) and Mills (1985).

Rationale of Sludge/fly Ash Treatment

The approach to this study was to recognize that the physical problems on smelter-contaminated soils or other similar areas are as important as the toxic amounts of metals. Consequently, steps were taken to mitigate or ameliorate the physical problems and to select metals-tolerant ecotypes of desired species.

In 1984, it was proposed to the U.S. Environmental Protection Agency to attempt the reclamation of Blue Mountain in a manner never before tried. With the backing of the EPA due to the Superfund status of the site, an important new option now became available. This option was that some new and innovative approaches to reclamation could be tried that might be outside the permit requirements of state or local environmental regulatory agencies.

It was proposed to undertake greenhouse and field studies to determine the technical feasibility of reclaiming Blue Mountain using applications of limestone, potash, sewage sludge, and power plant fly ash as soil amendments, and then hydroseeding and mulching adapted species. Due to the extreme slopes on the hillsides, and due to the large amounts of dead trees and the rocky surface conditions, it was also proposed that the amendments be blown onto the soil surface and not incorporated. The assumption was that the amendments would wash off the dead trees and rocks into the "interstitial space" of exposed soil, which averaged 53%, and that vegetation would keep the new soil on site. Reclamation work of this nature is without precedent in the literature. Large amounts of literature are available on the use of either sludge or fly ash for land reclamation, but in all cases, the amendments were incorporated in the spoil material. The use of sludge and fly ash mixed together has been attempted only in greenhouse studies and only with incorporation into uncontaminated soils (Adriano and Page 1981, Adriano et al. 1982, and Adriano et al. 1982a).

The problems of alkalinity and high soluble salts that were identified in these studies would not be problematic in eastern Pennsylvania where alkalinity would probably be beneficial, and the soluble salts would leach from the soil profile rather quickly.

As shown in table 1, most of the major problems associated with reclamation of smelter-affected soils would be mitigated or solved by treatment with a sludge/fly ash mixture. The primary reasons for trying a combination of sewage sludge and fly ash are twofold. First, it was postulated that the handling characteristics of the mixture would be improved: Sludge at 15 to 20% solids can be quite sloppy when used alone, while fly ash is prone to dust generation. Second, the light color of the fly ash was thought to be beneficial for an unincorporated use, as it would lighten the dark-colored sludge, thereby helping to prevent excessive temperatures from developing at or near the soil surface. Additionally, it was felt that the fly ash, being composed of soil-sized particles, would help keep the sludge from crusting on the surface, thereby increasing the porosity, infiltration, and percolation rates of the mixture.

The use of either sludge or fly ash alone, without incorporation, would almost certainly fail in this application. The black sludge tends to dry and crust on the surface. This cracked surface repels water, which enters the cracks, moves below the sludge, and would move the sludge off the slope and off-site. Fly ash alone, without incorporation, would either dry and blow off the site or erode from the slopes during rainfall events.

GREENHOUSE STUDY

A greenhouse study was conducted from February 1986 to June 1986 as a preliminary step in determining if the application of a sewage sludge and fly ash mixture would be an effective technology for revegetating the defoliated portions of Blue Mountain. The greenhouse study was designed to evaluate the proposed amendments and to screen herbaceous species. The study was conducted at the USDA Soil Conservation Service Plant Materials Center, Corning, NY. The reader is referred to USEPA (1987) for more complete coverage of all aspects of both the greenhouse and field studies, as space is limited in this presentation.

Materials and Methods

Twelve herbaceous species were grown in containers with sludge or sludge/fly ash mixtures placed on top of contaminated soils. Open-bottomed half-gallon milk cartons were used as planting containers to facilitate removing the below-ground biomass following the study. Each container was 10 cm by 10 cm and 25 cm in height. All containers were filled with 2.5 cm of sand in the bottom, followed by 10 cm of contaminated surface soil collected from Blue Mountain. The next step was to treat all containers except the controls with the equivalent of 10 tons/acre of lime and the equivalent of 80 lb/acre K (132 lb/acre potash). The application rates for the lime and potash were determined by earlier soil tests to ascertain existing conditions. The sludge or sludge/fly ash amendments were applied next at a depth of 5 cm. Following this, the various species were seeded at a rate of 0.4 g/pot, which is equivalent to 40 lb/acre, and mulched with the equivalent of 3,000 lb/acre of cellulose fiber mulch. Greenhouse temperatures were maintained at 20-22^{o} C, supplemental 24-hour light was provided, and the study was conducted for 98 days.

Treatments consisted of five amendments and a control. Each treatment was replicated three times to provide enough biomass to conduct metals uptake analyses for both the above- and below-ground biomass. The six treatment combinations used the following mix ratios:

1) 1 Sludge (1S)
2) 1 Sludge : 1 Fly Ash (1S:1FA)
3) 2 Sludge : 1 Fly Ash (2S:1FA)
4) 3 Sludge : 1 Fly Ash (3S:1FA)
5) 3 Sludge : 1 Fly Ash [with the addition of 2.5 cm humus between the soil and the amendment (3S:1FA:H)]
6) Control (Commercial potting medium only)

The amount of sludge applied in all treatments was constant, while the fly ash varied, e.g., the 2:1 treatment contained one-half the amount of fly ash that the 1:1 treatment had. All sludge and fly ash amendments were prepared on a volume basis. The amount of sludge applied per treatment was equivalent to applying 2,000 lb/acre total organic nitrogen.

Earlier site evaluation on Blue Mountain revealed the presence of significant amounts of a black humus which appeared to be undecomposed leaves and tree bark. Subsequent laboratory analysis indicated that this humus contained the highest recorded metals values on the mountain, so Treatment 5 was added to the experiment to determine if this humus would have an adverse effect on revegetation attempts.

The sludge used for the study was obtained from the City of Allentown, PA, and the fly ash was obtained from the Pennsylvania Power and Light Co. generating station at Washingtonville, PA.

The species planted were as follows: 1)'Oahe' intermediate wheatgrass, Agropyron intermedium; 2) 'Streeker' redtop, Agrostis gigantea; 3)'Niagara' big bluestem, Andropogon gerardi; 4) tufted hairgrass (PI-314562), Deschampsia caespitosa; 5) 'KY-31' tall fescue, Festuca arundinacea; 6) common goatsrue (PI-283238), Galega officinalis; 7) 'Lathco' flatpea, Lathyrus sylvestris; 8) 'Pennfine' perennial ryegrass, Lolium perenne; 9) 'Empire' birdsfoot trefoil, Lotus corniculatus; 10) 'Blackwell' switchgrass, Panicum virgatum; 11) 'Aldous' little bluestem, Schizachyrium scoparium; and 12) kura clover (PI-T12818), Trifolium ambiguum.

Results and Discussion: Greenhouse Study

Germination and Height Growth

Eleven of the twelve species studied germinated and grew in all replications of all six treatments. The exception was common goatsrue (Galega officinalis), which did not germinate in any treatment, including the control. This is believed to be due to an extremely hard seed coat.

With few exceptions, either the 3S:1FA or the 3S:1FA:H treatment yielded the greatest heights. The exceptions were redtop (2S:1FA), and perennial ryegrass (1S). The growth differences were, for the most part, not significant among treatments and show that these species will germinate and grow on the contaminated soils of Blue Mountain when it is properly amended. The percent cover was much more uniform across treatments, with up to 100% cover appearing in each treatment, varying with the species. A vigor analysis among species and across treatments revealed that a fairly steady decrease in plant vigor is seen across species when treatments are compared. The treatments having the greatest vigor were the 3S:1FA and the 3S:1FA:H with a steady decrease down through the 1S treatment. The highly contaminated humus did not have any adverse effects for the length of this study.

Root Development

Root growth was fair to excellent across all treatments, species, and replications. Roots grew through the amendments, contaminated soil, sand, and out the bottom of the pots. The best root growth correlated with the best above-ground plant performance, as expected. The treatments with the best root growth were the 3S:1FA and 3S:1FA:H.

Total Plant Biomass

Whole-plant dry weights were determined before separating the plants into above- and below-ground portions for metals uptake analysis. Although most species did not differ significantly across treatments, the 3S:1FA:H treatment had the highest total dry plant weight in 50% of all occurrences, followed by the 3S:1FA with 25%, and finally the 2S:1FA treatment with 17% of all occurrences.

When evaluated across species, switchgrass was the highest producer of biomass, followed by tall fescue, perennial ryegrass, intermediate wheatgrass, and big bluestem. After big bluestem, there were significant drops among the grasses. Among the legumes tested, flatpea and birdsfoot trefoil were the greatest producers.

The types of grasses included in this study are both warm-season and cool-season species. The warm-season grasses, i.e., big bluestem, switchgrass, and little bluestem, usually require 1 to 3 years to become fully established on a site, but once established are extremely long-lived and tolerant of harsh site conditions. In spite of the relatively short length of the greenhouse work (98 days), the warm-season grasses performed extremely well.

Among other differences between the warm-season and cool-season grasses, several concern the use of these species in the Blue Mountain work. The cool-season species are quick to establish, but tend to have several major disadvantages. For example, the cool-season grasses do not send roots much deeper than 10 to 12 inches, while the warm-season species can extend roots from 5 to 8 feet deep on droughty sites.

In the case of Blue Mountain, the extremely high concentrations of heavy metals predominantly are chemically bound in the upper 8 to 10 inches of soil. For the cool-season species, then, most of the roots may never escape the contaminated zone, while the warm-season species may have 80% or more of their total root mass below the contaminated zone. Additionally, the warm-season grasses are much more efficient users of available moisture and nutrients.

Because of these differences in growth habits, although the cool-season grasses establish quicker, their persistence on a site this toxic as compared to the long-lived warm-season grasses needs to be monitored.

Chemical Analysis of Foliage and Roots

Foliar N for the grasses generally ran two to three times higher in the amended pots than for the control pots. N levels were fairly steady across all treatments. Birdsfoot trefoil and kura clover, both legumes, had similar N concentrations even in the control pots, which would be expected due to their N-fixation ability. Flatpea, also a legume, showed a response more typical of the grasses, which may indicate some problem with nodulation by the correct Rhizobium sp. P, K, Ca, and Mg concentrations, while variable among species, remained relatively stable across treatments. Levels of all four elements were within a normal range.

Table 2.--Suggested permissible tolerance levels of trace metals in agronomic crops.[a]

Element	Suggested tolerance level
	ug/g
B	100
Fe	750
Mn	300
Al	200
Zn	300
Cu	150
Cr	2
Pb	10
Co	5
Ni	50
Cd	3

[a]From Council for Agricultural Science and Technology (1976), Melsted (1973), University of Georgia Cooperative Extension Service (1979), and Adraino (1986).

The analysis for trace metals found that the tolerance levels for agronomic crops listed in table 2, were not exceeded for Mn, Cu, Ni, and Co. Boron was below the tolerance level across all treatments except for perennial ryegrass in the 2S:1FA treatment. Cr, Al, and Fe concentrations varied widely among species and treatments, and were generally above tolerance levels for yield suppression of agronomic crops. Zn and Pb levels were relatively low. As expected, the levels were higher in the treatments with the humus. Only perennial ryegrass and birdsfoot trefoil exceeded the tolerance levels for both Zn and Pb. Tufted hairgrass exceeded the Pb level only, and tall fescue exceeded the Zn level only. Cd concentrations exceeded the tolerance levels in 8 of the 11 species. The only species below the tolerance level were big bluestem, little bluestem, and flatpea. Peak Cd concentrations were generally in the 3S:1FA:H treatment for all 11 species, because of the high amount of Cd in the humus.

Analyses of the roots were performed for all elements that the foliage was analyzed for, with the exception of N. Only Zn, Cd, and Pb uptake will be discussed here.

Generally, Zn, Cd, and Pb levels increased dramatically from the control pots through the various treatments. For the most part, levels rose from the controls to the 1S treatment, then decreased slightly at the 1S:1FA as a result of the liming effect of the fly ash, then once again climbed as the fly ash content decreased, finally peaking in the 3S:1FA:H mixture, due to the humus metals content.

CONCLUSIONS: Greenhouse Study

1. Of the twelve species seeded, only one, common goatsrue, Galega officinalis did not germinate, believed to be due to an extremely hard seed coat.

2. The best height growth by treatment was as follows:

- 3S:1FA -- 5 species -- big bluestem, tufted hairgrass, tall fescue, flatpea, and switchgrass.
- 3S:1FA:H -- 4 species -- intermediate wheatgrass, birdsfoot trefoil, little bluestem, and kura clover.
- 2S:1FA -- 1 species -- redtop.
- 1S -- 1 species -- perennial ryegrass.

3. All 11 surviving species grew well in the humus. Both root and shoot development appeared normal. No long-term survival data are available for plants growing on this high metal material, however.

4. Switchgrass, perennial ryegrass, and tall fescue had the best vigor ratings. The second best group of species for overall vigor were big bluestem, intermediate wheatgrass, and redtop.

5. The greatest amounts of biomass production by treatment were the 3S:1FA:H (six species); 3S:1FA (three species); and 2S:1FA (two species).

6. In general, the poorest plant performance occurred in the 1S treatment.

7. The root systems of all 11 surviving species grew through all amendments, the contaminated soil, and out the bottom of the containers.

8. Overall trace metal foliar concentrations were generally low and usually below the suggested tolerance levels for yield suppression for agronomic crops. In general, the warm-season grasses, i.e., switchgrass, big bluestem, and little bluestem accumulated much lower concentrations of foliar metals than did the cool-season grasses, i.e., redtop, tall fescue, perennial ryegrass, tufted hairgrass, and intermediate wheatgrass.

9. Trace metal concentrations in the roots were much higher than foliar levels.

10. The species that accumulated the least amounts of trace metals across all treatments was little bluestem.

11. This study demonstrated the technical feasibility of attempting to reclaim the metals-contaminated site on Blue Mountain by using this innovative reclamation technology.

Overall, the plants performing the best were switchgrass, tall fescue, intermediate wheatgrass, big bluestem, flatpea, perennial ryegrass, and birdsfoot trefoil. These species were retained for use in the field plots installed on Blue Mountain.

FIELD PLOT TRIALS

Based on the positive results in the greenhouse study, EPA approved the large-scale field plot trials on Blue Mountain. The intent of the field plot work was not only to test the soil amendments and herbaceous species, but also to test field-scale equipment. If the field work could not be completed in a cost-efficient manner using large equipment, the entire project would have to wait until equipment could be developed.

The field plots were installed by the City of Allentown's Department of Public Works. Allentown also supplied the sludge for the project. The fly ash utilized for the field plots was supplied by the Pennsylvania Power & Light Co.

Plot Layout

Ten 1-acre plots were laid out along a road bulldozed to provide access to the mid-slope portion of Blue Mountain. Three plots were located on the downslope side of the road, and the remaining seven plots were located on the uphill side of the road. The uphill plots were selected to test the spraying range of the equipment. Each 1-acre plot extended 150 ft. perpendicular to the road, and 290 ft. parallel to the road. For the herbaceous species, each plot was split into five subplots, 150 ft. deep by 58 ft. wide, for the seeding of five seed mixes. The plots were located in sets of three for application of the sludge/fly ash mixtures. Plot layout consisted of three replications of the 1S:1FA, two replications of the 2S:1FA, three replications of the 3S:1FA, one plot of a 3S:1FA mixture using sludge from the Borough of Palmerton, PA, which was very high in metals, and one plot as a control. The control plot received all amendments and seed/mulch as the other plots with the deletion of sludge and fly ash.

Application of Soil Amendments

Agricultural limestone and potash were applied to each plot using a spreader truck. Lime was applied at 10 tons/acre, and potash was applied at 132 lb/acre (80 lb/acre K). The limestone applied was approximately double the amount required to raise the soil pH to 7.0, but was used to help immobilize the large amounts of heavy metals in the soil. Next, the sludge and fly ash amendments were applied. To supply approximately 2,000 lb/acre of total organic nitrogen, an application rate of 21 dry tons sludge/acre or approximately 105 product tons/acre (20% solids) was used. The sludge amount was constant in all mixtures, as it was based on the N loading. The sludge and fly ash were mixed on a volume basis, so the amount of fly ash applied in the 1S:1FA ratio was 105 tons/acre; in the 2S:1FA ratio, the fly ash amounted to 52.5 tons/acre; and in the 3S:1FA ratio, 35 tons/acre of fly ash was used.

Initially, the sludge and flyash were mixed in the bucket of a large front-end loader, but this process was slow, and became the limiting factor in the operation. Several different methods were tried to accomplish the mixing in a more timely fashion until it became apparent that the products could be loaded into a dump truck used to ferry the amendments to the work area without mixing at all. The products were merely loaded into the dump truck, alternating layers of sludge and fly ash to achieve the desired ratio. Mixing occurred during transport to the work site, dumping, and loading into the spreader truck. The material was thrown forcibly from the rear of the spreader by a fan spinning at 12,000 to 18,000 rpm. The final products were evaluated once they had been applied, and the mix appeared to be as homogeneous by not mixing as it had been when fully mixed prior to application.

Composite samples of the sludge/fly ash mixtures were collected for chemical analysis as the amendments were applied on the plots. The actual amounts of each chemical constituent applied were close to design amounts, with the exception of Fe and Al. Concentrations of these two elements were much higher than earlier analysis had shown. Amounts of nutrients in the various mixtures ranged from 885 to 1,084 lb/acre of P, and from 2,192 to 2,705 lb/acre of N. For full soils, sludge, and fly ash chemical analyses, the reader is referred to USEPA (1987).

Hydroseeding of Grasses and Legumes

The 1-acre field plots had been subdivided into five subplots (1/5 acre each) for seeding prior to application of the amendments. The seed mixtures applied on each subplot are shown in table 3.

The plots were seeded on May 27 and 28, 1986 using a 900-gal. hydroseeder. On May 28-30, all field plots were mulched with cellulose fiber mulch at a rate of 2,000 lb/acre.

RESULTS AND DISCUSSION: Field Plot Trials

Plant Performance: 1986

Germination and emergence of most species began within 10 days following seeding. Plots were subsequently visited at 2- to 3- week intervals throughout the 1986 growing season. The earliest emergence was seen, as expected, in the cool-season grasses, i.e., tall fescue, perennial ryegrass, and intermediate wheatgrass. The next species to emerge were the warm-season grasses, switchgrass and big bluestem. Initially, there was a lack of legumes. The lack of legumes and the slower emergence of the warm-season grasses can probably be attributed to the late planting date. By the end of May, there were no more cool night temperatures to help these species break any remaining seed dormancy. Some bare areas within subplots can be attributed to "sprayer skips" by the hydroseeder.

Final data for 1986 were collected in mid-November. Data included: 1) number of plants/ft^2, 2) height, 3) vigor rating, 4) root development, and 5) tally of invading species. The method used was to construct a 3/16-inch steel cable hoop with an inside area of 1 ft^2. This hoop was then tossed randomly throughout each subplot to locate 25 sample points. All data were collected at each point.

Switchgrass had its best performance in the 1S:1FA treatment for number of plants/ft^2 and for height. The 2S:1FA ratio was intermediate, and the 3S:1FA was the worst performance.

Big bluestem, tall fescue, and birdsfoot trefoil all showed similar responses, with 1:1 best, 2:1 intermediate, and 3:1 worst. Flatpea, perennial ryegrass, and intermediate wheatgrass were not as clearly defined, but the 1:1 or 2:1 ratios were superior for either number of plants/ft^2 or height. Some of these variations can be a result of rockiness of subplots or similar environmental problems.

Root development was determined by digging one to three typical plants at each point and examining for color, amount of growth relative to shoot growth, normal development of root reserves, root hairs, and nondistorted appearance. Presence or absence of viable nodules was also checked on the roots of the legumes. In all cases, root system development was normal, unless a rock or restricting layer distorted growth.

Interestingly, there were very few to no nodules on the roots of the legumes. This may be the result of one of three possibilities: 1) the bacterial inoculant was dormant or had been heated before use, 2) the *Rhizobium* sp. did not nodulate in the presence of very high levels of N in the sludge, or 3) the levels of trace metals in the soil were so high that the *Rhizobium* sp. bacteria were killed.

The first of these three possibilities can be ruled out. The third possibility seems unlikely because the root segments in the sludge/fly ash mixtures had no more and no less nodulation than the roots in the contaminated soil. If the metals in the soil had been responsible for the lack of nodulation, there should probably be some nodules present above the soil, in the 1-1/2 to 2-inch thick layer of sludge/fly ash, unless the metals were being translocated through the roots, thereby destroying all *Rhizobium*, even those in the sludge-fly ash.

Table 3.--Species and seeding rates used on five field study subplots on Blue Mountain, PA.

Subplot #	Species	Rate(lb/acre)
1[a]	'Blackwell' switchgrass	15[c]
1[b]	'Cave-in-Rock' switchgrass	15[c]
2	'Niagara' big bluestem	30[c]
3	'Empire' birdsfoot trefoil +	20
	'Ky-31' tall fescue	40
4	'Pennfine' perennial ryegrass +	20
	'Lathco' flatpea	60
5	'Oahe' intermediate wheatgrass	30

[a] Seeded on field plots 2, 4, 6, 8, and 10.
[b] Seeded on field plats 1, 3, 5, 7, and 9.
[c] Pure live seed.

The second possibility, that the high levels of N in the sludge suppressed the Rhizobium activity is the most likely explanation. The possibility that the dormant inoculum can reside in the soil for several years until N levels decrease will need to be monitored. Possibly a top-dressing with additional inoculant will be necessary at some point in the future.

It was determined that the subjective vigor ratings were less useful than the measured ratings of plants/ft^2 and height, so vigor will not be discussed.

Plant Metals Uptake: 1986

Foliar samples only were collected in mid-November 1986 for chemical analysis. Birdsfoot trefoil and big bluestem were not collected.

N, P, K, Ca, and Mg were all within tolerable limits for all species across all sludge/fly ash ratios. Mn levels only exceeded tolerable levels in flatpea (1:1) and perennial ryegrass (1:1). All Fe levels were below the tolerable level. Cu concentrations were all well below the limit. B in all samples varied from 6 to 29% of the tolerable level.

Al uptake was varied. Switchgrass, flatpea, and perennial ryegrass exceeded the tolerable level in both the 1:1 and the 3:1 mixtures, but no adverse effects were seen on the plants. Tall fescue was under the limit in all ratios. Intermediate wheatgrass was over the limit in the 3:1 but within limits in the 1:1 ratio. Zn levels exceeded the tolerable level in all species and across all ratios except switchgrass in the 1:1 mixture. Pb was above the tolerance level in all species and all ratios. Cd was also above the tolerance level in all species and all ratios, but a definite trend developed showing the least uptake in the 1:1 plots and greater uptake in the 3:1 plots. Ni levels were all below the tolerance level. Cr levels in all species other than tall fescue slightly exceeded the tolerance level in all ratios. Finally, all Co levels were below the limit.

Many studies in the literature have shown that metals uptake by vegetation following sludge application is far greater in the first year than in subsequent years. Overall, metals uptake was not excessive, considering the site. Metals uptake should decline rapidly, but without harvest or other removal of vegetation, the metals uptake may remain higher than usual. This site will be monitored for many years in the future.

Overland Movement of Sludge/Fly Ash Mixtures

Because the amendments were not incorporated into the soil, it was anticipated that the sludge/fly ash mixtures would wash off the rocks and dead trees into the interstitial spaces to provide a growing medium. It was not anticipated that there would be any significant offsite movement. The average slopes within the plots ranged from 24 to 35%, with even steeper slopes for short distances within plots.

The sides and lower portions of each plot were examined throughout 1986 and 1987 for any evidence of overland movement. None was seen. After mixing the two materials, the handling characteristics improved greatly. The mixture is much more cohesive than either product alone. The amount of interstitial space (average 53%) was sufficient to hold the amendments on site.

One point to consider was the 1986 and 1987 precipitation. The long-term average precipitation for Palmerton, PA, is 40.5 inches. In 1986, a total of 53.02 inches was recorded, 12.52 inches above average. Only three other years have had more recorded rainfall since 1918. In 1987, two major rainfall events occurred, one in July, and one in October, both of which yielded in excess of 6.5 inches of precipitation in a short period of time. Following both of these events, several local highways were blocked with mudslides, and the access road on Blue Mountain to the plots washed out. Of significance, though, is the fact that no sludge/fly ash left the plots, even in storm events such as these. As of November 1987, there are still some standing dead trees that have had varying amounts of the sludge/fly ash mixture clinging to them since May 1986. The reader is referred to USEPA (1987) for full discussion and data for these findings.

Plant Performance: 1987

During the first week of May 1987, the field plots were visited for the first time of the growing season, and all plots other than the control had emerged remarkably well for this early in the season. Both the cool- and warm-season grasses were quite vigorous, but a noticeable lack of legumes was evident. During the 1986 growing season, the lack of legumes was attributed to the late planting date, and it was hoped that by stratifying over winter, more legumes would have germinated from the hard seed. This was not the case, however.

The plots were subsequently visited at 2- to 3-week intervals through November 1987, and no additional emergence of either birdsfoot trefoil or flatpea was noted. Both of these species compose less than 5% of the stands in the subplots where they were planted.

Final data were collected on plant performance in mid-October, 1987. Data were limited to: 1) plant height; 2) percent stand; and 3) chemical analysis of foliage samples. The rather dramatic differences in the various sludge/fly ash ratios seen in 1986 had diminished somewhat, with the 2S:1FA mixture essentially catching up with the 1S:1FA ratio. The 1987 data have not yet been published, as was the case for 1986, so (table 4) contains the mean values of the replications for each species and mixture.

As can be seen in (table 4), the 1S:1FA ratio contains four maximum values, the 2S:1FA ratio contains five maximum values, and the 3S:1FA mixture only contains one maximum value. Only the perennial ryegrass had its maximum height growth in the 3S:1FA ratio, but the percent stand was the lowest of the three ratios.

Table 4.--1987 Plant performance summary.

	Sludge/fly ash ratio					
	1S:1FA		2S:1FA		3S:1FA	
Species	ht.cm	%stand	ht.cm	%stand	ht.cm	%stand
Switchgrass	33.1	73.7*	34.4*	60.8	26.2	42.6
Big bluestem	35.7	55.6	36.6*	55.7*	30.8	38.1
Tall fescue	32.6*	78.3	28.6	79.8*	22.7	50.0
Birdsfoot trefoil	--	--	--	--	--	--
Per. ryegrass	21.8	72.8	20.7	76.2*	23.1*	69.3
Flatpea	--	--	--	--	--	--
Inter. wheatgrass	29.4*	72.4*	26.1	65.7	18.3	56.2

*Represents greatest value for that species within that data field.

While additional work needs to be done to define the most efficient ratio, both economically and environmentally, it appears at this point that either the 1:1 or the 2:1 have the most merit from a plant growth perspective. Economically, the less fly ash that is used, the less the entire operation costs in materials and time. Additionally, since the fly ash is abrasive on the spreading equipment, the lower amount of ash prevents wear.

Concurrent with observations of plant performance made in the field plots during 1987, the return of a considerable amount of wildlife was noted within the plots. Species seen include white-tailed deer, groundhogs, white-footed mice, shrews, meadow voles, kestrels, and bluebirds. Insect life is quite abundant with a large number of spiders, crickets, grasshoppers, leaf hoppers, etc. Within the plots, decomposition of some of the dead trees has begun, indicating a return of microbial activity to this one-time biological desert.

CONCLUSIONS: Field Plot Trials

After two growing seasons, the field plots indicate that it is indeed possible to reclaim areas thought to be impossible. Extremely disturbed sites such as this with lingering toxicity problems can be revegetated, but require innovative techniques.

In September 1987, the Regional Administrator for the EPA signed a Record of Decision for the Blue Mountain project, which means that the Remedial Investigation/Feasibility Study portion of this project was concluded, and full-scale remedial action will begin. Actual work on the site will begin as soon as Remedial Design, legal negotiations, etc., are concluded. The Blue Mountain project is the largest single revegetation action ever undertaken by the EPA Superfund program, and it is intended to serve as a model of innovative technologies for other sites. One real advantage of this technology is that the financial costs of the project will be borne by the various municipalities contributing the sludge, and these municipalities are expected to accrue substantial savings over current landfill costs. This project, then addresses not only the reclamation of a toxic mountain, but also the disposal problems associated with municipal sludge and power plant fly ash.

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BOISSEVAIN RECLAMATION PROJECT

A MULTIDISCIPLINARY APPROACH TO ABANDONED MINELAND RECLAMATION[1]

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Abstract.—A team of scientists and engineers was employed to design reclamation measures on an abandoned mineland project in northwestern Virginia. The project area consisted of coal refuse stored in randomly placed piles and in the floodplain of a local stream. An environmental assessment of the site identified the potential hazards from flooding and refuse sliding, erosion, and aesthetics as major problems. Reclamation alternatives were formulated along with environmental impacts and cost estimates. The reclamation alternative chosen included regrading the refuse piles into safe configurations, removing refuse in and along Laurel Fork, installing permanent drainage features, and revegetation of the existing refuse material. Conventional construction equipment and methods were used in the earthwork phase of the project. Revegetation included heavy application of lime and fertilizers based on refuse sample analyses. White pine (Pinus strobus) and autumn olive (Elaeagnus umbellata) seedlings were hand planted on the reclaimed outslopes. After one year of growth, total vegetative cover was about 50% with approximately 60% tree seedling survival. Scattered areas throughout the project area required maintenance revegetation treatments, partly because of a very dry spring and summer. Four years after reclamation, approximately 80% cover had been achieved with good survival and growth in the autumn olive seedling and poor results with white pine seedlings. The success of the project was due to an effective assessment of the problem and the formulation and implementation of a cost-effective, workable plan.

Additional Key Words: coal refuse, revegetation, white pine, autumn olive, Virginia.

INTRODUCTION

Since the Surface Mining Control and Reclamation Act of 1977 was enacted, government agencies and the private sector have cooperated to rehabilitate several thousand acres of useless or abandoned land. Commonwealth Technology, Inc. has employed a multidisciplinary approach to design reclamation measures on many abandoned mineland projects in Kentucky, Ohio, Virginia, and West Virginia in the past 7 years. Design engineers, soil scientists, geologists, hydrologists, and biologists offer unique insight into abandoned mineland problems sometimes overlooked. This paper reports on one such project administered by the Commonwealth of Virginia, Division of Mined Land Reclamation. The site, as shown in Figure 1, was located in northwestern Virginia near the community of Boissevain which was constructed in the early 1900's when the Pocahontas No. 3 Coal Seam was mined. In the 1970's, much of the refuse was removed for reprocessing and the remaining waste was spread along the banks of Laurel Fork, the major tributary flowing through Boissevain. Additional placement of refuse occurred in one of the small hollows on site. Primary goals of the project were to reduce the potential for flooding along Laurel Fork, reduce sediment production from unvegetated areas, and to improve the site aesthetically.

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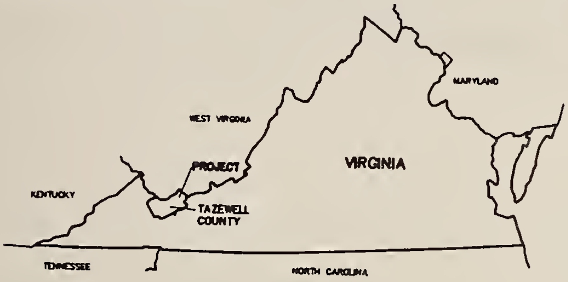

Figure 1. -- Boissevain Reclamation Project site.

PROBLEM ASSESSMENT

In order to determine the impacts of the refuse dump on the environment, a team of professionals of various disciplines was assembled to investigate the problem. The team included design engineers, a biologist/hydrologist, a geologist, a soil scientist/forester, and a field survey crew.

Surface water runoff from the project is received by Laurel Fork, a tributary of the Bluestone River. Laurel Fork is a second-order stream which drains 6.5 mi at the project site. The project site is shown in Figure 2. Forestland is the major land use in the basin. Domestic sewage discharge from local residents also flows into Laurel Fork throughout its reaches. Five surface water stations were monitored to assess background water quality. The stations included an upstream station for control as well as four sites affected by the refuse dump. The results indicated an increase in iron, manganese, and suspended solids at the stations receiving runoff from the refuse site. Two of the stations, one upstream and one affected by the refuse, were sampled for aquatic biology. The Simpson Diversity Index (Brower and Zar, 1977), which is a ratio of population species to population numbers, was determined to be 0.48 and 0.58 at one upstream station and one downstream station. monitoring stations. A second-order stream, such as Laurel Fork, could be expected to have a macroinvertebrate diversity value in the 0.7-1.0 range. At the time of the aquatic survey, streamflow was low and no significant runoff from the refuse dump was occurring. After further investigations, it was determined that the flat stream gradient evident at both sampling sites was partially due to placement of refuse in and along Laurel Fork causing pool conditions upstream of the site. The stagnant conditions created by the siltation from the area, partially blocking culverts on Laurel Fork, in combination with the input of domestic sewage were the chief causes of low stream fauna diversity.

A survey of ground water users in the vicinity of the project area revealed that most residents used the public water upstream provided by the community of Boissevain. Three residents near the project utilized a spring for domestic water. Analysis of a sample from the spring indicated favorable water quality with no apparent effects from the refuse dump. The environmental assessment team also examined land use patterns, vegetation communities, and wildlife inhabitants in the project area. Most of the land in the area is forested, especially the hillsides and upland areas. The valley bottoms contain the roads, railroads, and residential and commercial development. The forestland is second-growth complex of climax and subclimax communities with oak-hickory forest-type dominating. No rare or endangered vegetative species were observed in the project area. A less significant effect of the refuse dump was the reduction of forestland and associated wildlife habitat at the project site.

In the project area, the exposed strata outcropping were from the Lee Formation. The Pocahontas Coal No. 3, the source of the project refuse, lies at the base of the formation and has also been described as part of what has been called the Pocahontas Formation. Structurally, the refuse area was situated on the northern side of a structural boundary marked by a fault line that roughly parallels Laurel Fork and has been called the Abbs Valley Fault. To the north of this fault, the strata are under the influence of the Dry Fork anticline. This feature has resulted in a mild southeasterly dip of most strata although localized anomalies exist where dip may vary significantly. To the south of the fault, the Abbs Valley anticline is a major feature. At the southern edge of the project area, the strata have been folded and truncated as a result of tectonic activity and erosion.

The existence of faulting coupled with anticlines on both the north and south has the effect of concentrating ground water flow along the Laurel Fork watershed. Movement is downdip toward the fault from the Dry Fork anticline and the folding and inclination of strata along the southern edge of the area provide additional ground water flow at this site. A drainage feature was constructed during mining operations on the Pocahontas No. 3 Coal Seam to discharge ground water. Failures or blockage of this drainage facility could result in significant increase in the water table level along Laurel Fork.

The naturally occurring soils of the project area are the residual soils of the uplands - Wellston and Muskingum series; and the alluvial soils such as Dunning, Pope, Philo, Atkins, Huntington, Linside, and Melvin (Southwest Virginia 208 Planning Agency, 1978). The remaining soils at the site are the minesoils, which consist of weathered refuse material alone, mixed with the naturally occurring soils. The minesoil was black to dark brown with iron-staining on coarse fragments which ranged from 1 cm to 12 cm in diameter. Composite samples of the refuse (minesoil) were collected and analyzed for acid-base parameters and metal composition. Samples of topsoil from the forested area adjacent

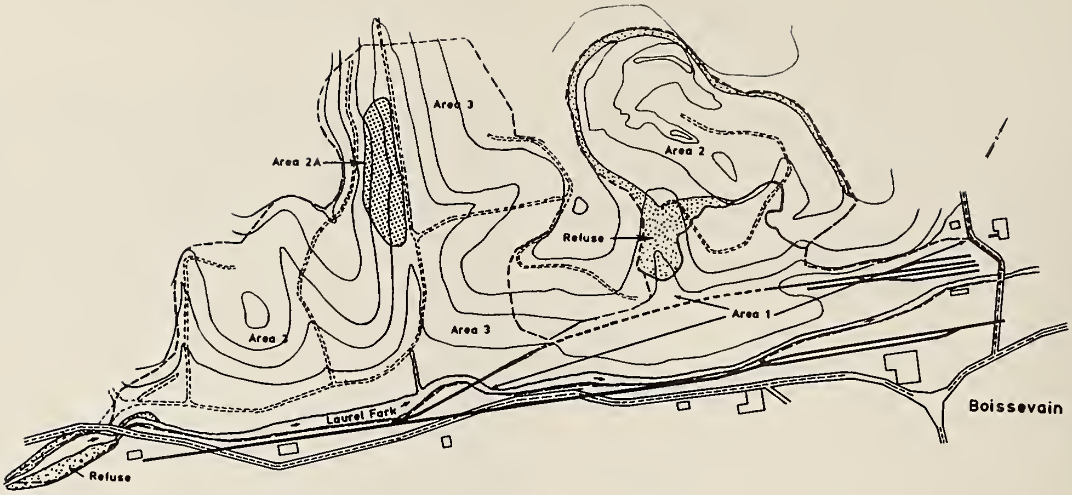

Figure 2. -- Project area showing existing refuse placement.

to the site were also collected and analyzed as potential borrow material. The results of the analysis revealed near neutral minesoil with high reserve acidity. A lime requirement of 14 to 18 tons/acre was indicated by the analysis to neutralize the reserve potential acidity. The borrow area topsoil was slightly acidic, requiring approximately 6.5 tons of lime/acre. Due to the qualities of the available borrow material and the additional costs of clearing and revegetating the borrow area, it was concluded that using the borrow area topsoil to reclaim the site would not be feasible.

The environmental assessment process also included a determination of archeological, historic, and recreational sites which might be affected by the project. This task was accomplished by a field examination of the project area and by contacting the appropriate local and state agencies such as the Virginia Historic Landmarks Commission and others. The investigation revealed that the project would not affect any such sites as none existed in the immediate vicinity of the project area.

DEVELOPMENT OF RECLAMATION ALTERNATIVES

After the problem assessment phase was completed, alternative reclamation plans were formulated and their impacts on the environment were determined. Four reclamation alternatives were developed. The environmental impact categories included surface water hydrology, fish and wildlife habitat, vegetative resources, aesthetics, public health and safety, land usage, and recreational resources.

Alternative No. 1 was to take no remedial action whatsoever. Problems such as flooding, stagnant water, erosion, and unappealing aesthetics would persist. The refuse area was marginally stable and slides of large quantities could develop which would accelerate erosion and sedimentation problems in Laurel Fork. Sliding would also expose pyrite in the refuse to further production of acid and would further degrade surface water quality and existing vegetative resources. Under this no-action alternative the aquatic and terrestrial habitat would not be enhanced and might be further depleted by refuse sliding. As previously mentioned, public health and safety concerns, primarily flooding and slides, would not be served under Alternative No. 1.

Reclamation Alternative No. 2 involved creating a valley refuse fill area on site with surface drainage and discharge facilities. Areas with sparse vegetation would receive localized revegetation treatments including lime, fertilizer and seed and mulch. The plan also proposed streambed improvements to eliminate ponding. The estimated cost of Alternative No. 2 was $641,250.

Reclamation Alternative No. 3 was similar to Alternative No. 2 except that disposal of the refuse would occur offsite. It was determined that about 30 percent of the refuse was coal and could be recovered. An offsite disposal area of approximately 10 acres was proposed. This alternative proposed the reclamation of the refuse site and disposal area, reseeding, liming and fertilizing sparse vegetation areas, and streambed improvements. The estimated cost of Alternative No. 3 was $1,781,875. Revenue from sale of reprocessed coal was not included in the cost estimate for Alternative No. 3 since Consolidated Coal had ownership rights.

Alternative No. 4 was directed at the alleviation of adverse existing conditions with minimal work on the refuse area. The hydrologic work consisted of streambank restoration to drain ponded water of Laurel Fork and to improve discharge capabilities. This plan included the stabilization and in-place reclamation of refuse piles and minimal revegetation work on sparsely covered areas. The estimated cost for Alternative No. 4 was $304,607. Table 1 contains the estimated costs by item for each of the three action alternatives. Reclamation Alternatives

TABLE 1.--ESTIMATED COSTS FOR RECLAMATION ALTERNATIVES

	ALTERNATIVE NO. 2		ALTERNATIVE NO. 3		ALTERNATIVE NO. 4	
ITEM	QUANTITY	COST*	QUANTITY	COST	QUANTITY	COST
Refuse Excavation and Placement Area 2	60,000 CY	300	300,000 CY	1,525**	--	--
Drainage Facilities Excavation and Riprap Areas 2 & 3	4,000 CY	72	--	--	1,000 CY	18
Grading Areas	34.5 Ac	34.5	--	--	42 Ac	48
Revegetation	46 Ac	47	46 Ac	73.5	26 Ac	37.8
Stream Work Grade Improvement	1,400 CY	35	1,400 CY	35	1,400 CY	35
Stream Excavation	--	--	--	--	4,300 CY	43
CONSTRUCTION COSTS		488.5		1,633.5		181.8
OTHER COSTS***		152.7		148.4		122.8
TOTAL COST		641.2		1,781.9		304.6

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* Costs are in thousands of dollars.

** Cost includes purchase of disposal site.

*** Other costs include the following:

1) Operation and maintenance for 5 years.
2) Cost of permanent facilities.
3) Planning and engineering costs.
4) Environmental monitoring.
5) Upstream road improvements.

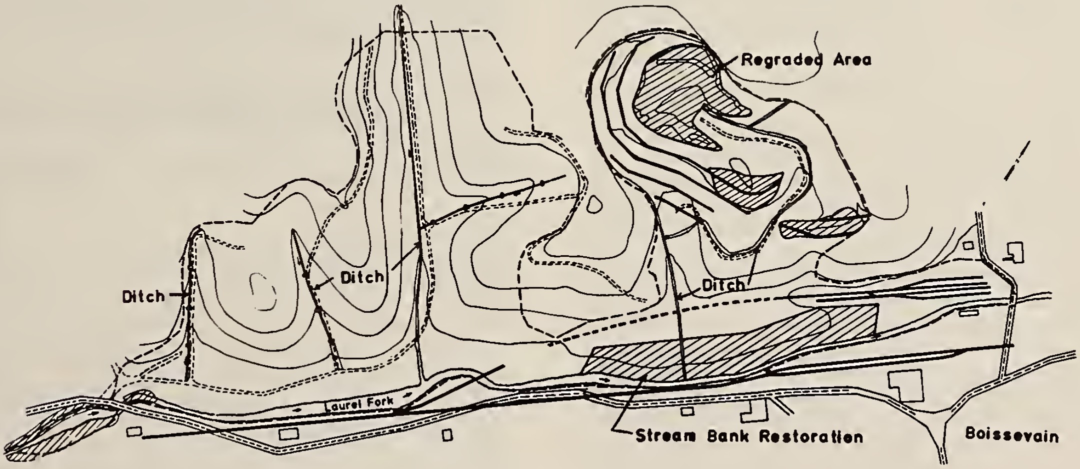

Figure 3. -- Project area after reclamation showing fill areas and drainage ditches.

Nos. 2, 3, and 4 included 5-year operation and maintenance cost estimates of approximately $56,000 for Alternatives No. 2 and 4 and $72,000 for Alternative No. 3.

The environmental impacts on the project area were similar for all three action alternatives. Surface water quality should improve by eliminating stagnant ponded water and by reducing sedimentation. As a direct result the aquatic biology should improve with improved water quality. Additional terrestrial wildlife habitat would also be created by the reclamation of previously denuded areas. Aesthetically, all three action alternatives would improve the site greatly by removing or covering unsightly refuse and trash scattered along Laurel Fork and in the refuse piles themselves. Perhaps the most important concern of the proposed reclamation alternatives is their effect on public health and safety. Two major areas of concern are the increased potential for flooding caused by placement of refuse in and along Laurel Fork and the potential for slides in the refuse piles. The action alternatives would reduce the potential for flooding through drainage controls and grading improvements in and along Laurel Fork. The potential for refuse slides would also be eliminated by the action alternatives. Other minor positive environmental impacts from the action alternatives include an increase in recreational resources, vegetative resources, and usable land base.

After careful review of the four reclamation plan alternatives by the Virginia Division of Mined Land Reclamation, Alternative No. 4 was selected for implementation with minor modifications. With the exception of planning and engineering costs listed in the category of Other Costs in Table 1; the other items were rejected. These included costs associated with operation and maintenance, environmental monitoring, and upstream road improvements. Commonwealth Technology, Inc. was contracted to develop construction plans and specifications.

CONSTRUCTION

Construction began on the project in January 1983 with clearing and grubbing activities. Channel improvement work on Laurel Fork was started and included the removal of coal refuse and trash along the banks of Laurel Fork. Grading work on the refuse piles began in February 1983 using conventional earth-moving equipment. Excess material was placed in a small hollow fill and compacted to the desired density using a sheepsfoot roller. As the refuse piles and fill areas were graded to new contours, benches and ditches were installed at effective locations. Figure 3 shows the regraded surface contours and construction features. Revegetation activities began in mid-March 1983 with the application of agricultural lime on graded areas. Lime was applied in two steps. First, 10 tons of lime/acre was applied and incorporated into the refuse to 12 inches using a disk harrow. The remaining 5 tons of lime/acre were applied and disked lightly. All lime was applied with conventional dry spreaders with side casting capabilities to reach outslopes. Seedbed preparation was performed by disking areas to receive revegetation treatments, especially the areas with sparse vegetation. Lime and fertilizer rates were determined from composite refuse/soil samples collected throughout the project area the previous year. The required fertilizer analysis and rate included 350 lb/acre of diammonium phosphate (18-46-0) and 100 lb/acre of muriate of potash. The fertilizers were applied in a slurry mixture with the seed and mulch using a hydraulic spreader. The following seed mixture and rates were used on the project area (Table 2).

TABLE 2.--SEED MIXTURE AND APPLICATION RATES ON REFUSE SPOIL IN PROJECT AREA

SPECIES	RATE (lbs/Acre)
KY Tall Fescue (Festuca arundinacea)	35
Sericea Lespedeza (Lespedeza cuneata)	20
Perennial Ryegrass (Lolium perenne)	20
Birdsfoot Trefoil (Lotus corniculatus)	10

Species selection was designed to provide both erosion control and long-term site protection. The contractor had the option of using one of the following mulch treatments:

Woodfiber mulch - 1,500 lbs/Acre plus binding agent
Hay or straw mulch - 1-1/2 tons/Acre plus asphalt tackifier
Hardwood bark mulch - 45 yds /Acre

Woodfiber mulch was the mulch option selected by the contractor. The seed, fertilizer, mulch, and binding agent were applied simultaneously using a hydraulic seeder.

On the area with existing herbaceous cover with scattered pine saplings, 5 tons of lime, 350 lbs/Acre of diammonium phosphate, 100 lbs/Acre muriate of potash, and the following seed mixture and rates of application were applied (Table 3).

TABLE 3.--SEED MIXTURE AND APPLICATION RATES ON AREAS OF EXISTING COVER IN PROJECT AREA

SPECIES	RATE (lbs/Acre)
KY 31 Tall Fescue	30
Sericea Lespedeza	20
Perennial Ryegrass	20
Birdsfoot Trefoil	10

Application of seed, fertilizer, and mulch was made using a hydraulic seeder, and lime was applied using conventional agricultural lime spreading equipment.

The final phase of revegetation was tree seedlings planting. Nursery-grown one-year-old eastern white pine (Pinus strobus) and autumn olive (Elaeagnus umbellata) seedlings were hand planted on the outslopes of the graded refuse. Approximately 375 seedlings of each species were planted at an approximate spacing of 10 feet between seedlings in a row and 10 feet between rows. Revegetation was completed in late April, 1983. By the summer of 1983, it became apparent that the drainage ditches installed using a filter fabric liner had not functioned properly. The corrective action taken was to replace the filter fabric in the ditches with rip-rap. All areas disturbed were revegetated as per contract specifications.

The remedial work was performed by the original contractor in August 1983. Vegetative cover was established successfully on virtually the entire project area by early summer. Lack of rainfall during the summer months stunted the herbaceous cover established on the project area. Some areas of sparse vegetation remained through the following spring (1984). A contract for revegetation maintenance was awarded for 10 acres on the project area. Areas with unsatisfactory vegetative cover received maintenance treatments in May 1984 (Table 4). The total construction costs were $180,000 which was about $100,000 less than projected costs.

TABLE 4.--MAINTENANCE TREATMENTS IN AREAS OF UNSATISFACTORY VEGETATIVE COVER

SPECIES	RATE (lbs/ACRE)
KY 31 Tall Fescue	10
Sericea Lespedeza	5
Weeping Lovegrass (Eragrostis curvula)	2
Pearl Millet (Pennisetum americanum)	20
Ryegrass	15
Fertilizer	
Ammonium Nitrate	100
Mulch	
Wood Fiber Mulch	1000

RESULTS AND DISCUSSION

One year after seeding, the work was evaluated. By this time the dominant components of the herbaceous stand were fescue and birdsfoot trefoil. Percent cover was estimated to be approximately 50 percent. The best vegetative cover was achieved on flatter surfaces, shaded areas, and in the small depressions created by the disk and dozer tracks. Obviously, the ability to hold moisture for plant growth became very important during the first summer of growth when rainfall was lacking.

Moderately high survival rates were observed in both the autumn olive and white pine seedlings after one year. Estimates of survival ranged from 50 to 70 percent for both species planted. The white pine seedlings were taller after one year, averaging approximately 30 cm while the autumn olive seedlings were about 15 cm tall. The difference in height is not all due to first season growth since the pine seedlings averaged 10 cm taller than the autumn olive seedlings when planted. Composite soil samples collected from the refuse area indicated that the soil remained nonacid with pH values of 7.3 and 8.0. Nutrient levels were moderately high also. Average levels of available nitrogen, phosphorus, and potassium were 28 lbs/acre, 45 lbs/acre, and 232 lbs/acre, respectively.

Four years after reclamation, the site was revisited. By this time the site was well covered with herbaceous plants. The dominant components were serecia lespedeza and birdsfoot trefoil. Fescue was also observed below the canopy of the dominant species. Percent cover was estimated to be at least 80 percent. In a typical area, the serecia and birdsfoot trefoil were almost a meter in height. Of the tree seedlings planted, the autumn olive appeared to survive and grow better. Several of the olive trees were 2 meters in height. The white pine did not fair nearly as well. Survival was estimated at 10 percent with those surviving being stunted, probably from the herbaceous competition.

Vegetative cover on the areas with sparse vegetation responded well to the applications of lime, fertilizer, and seed. Serecia lespedeza dominated the area with lush growth. Several white pine saplings existing prior to the reclamation also responded favorably to the treatments. Several of these trees were over 6 meters in height having grown approximately 3 or 4 meters in 4 years. Revegetation of the site and the installation of permanent drainage ditches significantly reduced erosion from the site and sedimentation in Laurel Fork. The excavation of sediment and debris in and along the banks of Laurel Fork through the project area noticeably improved water flow through the project area and partially eliminated ponded water conditions of the upstream end of the project area. Although no water quality monitoring has been performed after construction due to lack of funding, it is evident that water quality has improved with the improved hydraulics and the significant reduction in sedimentation. No evidence of landslides or land mass movement has been observed in the regraded refuse since reclamation.

CONCLUSIONS

Most often a reclamation project is judged on the basis of revegetation alone; consequently it is typically a major goal of such reclamation projects. Revegetation plans should be made by an experienced soil scientist, agronomist, or other professional and should be custom-made for a specific site. Assessment of the problem and collection of preliminary data are essential steps in formulating reclamation plans. Recognition of financial constraints and cooperation with the administering agency are also essential elements in reclaiming abandoned mine lands.

The success of the Boissevain Reclamation Project was a result of several factors including: an effective approach to problem assessment including determination of goals, utilizing the expertise of several science disciplines; the formulation of a cost-effective workable plan designed to achieve the stated goals; and the effective implementation of the plan. While the materials and methods used to successfully reclaim the Boissevain site would not be effective in every situation, the approach to problem evaluation and design plan formulation employed on this project can contribute to the successful conclusion of most reclamation projects.

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COAL SURFACE MINE REVEGETATION IN THE EASTERN U.S.[1]

E. S. Lyle, Jr.[2]

The Surface Mining Control and Reclamation Act of 1977 has provided a system of regulation that assures the revegetation of lands that have been surface mined for coal. However, this same system of regulation is, at times, too rigid and often prevents the utilization of known methods and vegetation systems that would be better for the environment, the local economy, and the efficiency of the coal mining operation. In most cases, the mining companies have concentrated on pleasing the regulatory agency by using vegetation and methods that will result in the least friction between the regulatory agency and the mining company. In many cases, this is not best for the environment, local economy or reclamation efficiency.

One example of the effect of the SMCRA on local economy is seen in Alabama. Before the passage of SMCRA, revegetation in Alabama consisted almost exclusively of reforestation. This was good for local economies since forestry is the leading industry in Alabama and provides much employment in the coal mining region. After the implementation of the SMCRA, most of the revegetation is accomplished with grasses and legumes. There is no grazing industry in the state and these grasses and legumes will slowly revert to a mixed forest of little economic value to the landowner.

There is a provision for Experimental Practices in Section 711 of the SMCRA. However, this section is seldom implemented. Researchers and mining companies should be encouraged to improve present revegetation practices through use of this provision.

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[1] Abstract of Mr. Lyle's remarks at the Plenary Session. His paper is available from Mr. William T. Plass, Executive Secretary, ASSMR, 21 Grandview Dr., Princeton, WV 24740

[2] E. S. Lyle, Jr. is a Land Reclamation Consultant.

GENETIC VARIATION OF BLACK LOCUST SEEDLINGS ON RECLAIMED SURFACE MINE SOILS[1]

Michael R. Bridgen[2]

Abstract.--Surface mining of coal frequently is done on forestry-based industrial lands in West Virginia. The resulting plant competition following reclamation inhibits the reestablishment of natural hardwood forests. Black locust (Robinia pseudoacacia L.) is a successful, fast growing hardwood when planted on these sites. Studies were established to determine how much genetic variability exists in black locust and which sources are the most desirable for planting on surface mined lands. Three experimental plantings have been established in Greenbrier County, WV, since 1984 from seed collected throughout the range of black locust. The oldest plantation has 30 seedlots from across the species' entire range. Genetic variation has been observed in leaf nutrient and chlorophyll variation. Height variation has also been observed. No geographic patterning has been associated with the variation. Selected seedlots can be identified which are expected to be superior sources.

INTRODUCTION

The state of West Virginia has an abundance of natural resources including forests and minerals. Over 75% of the state is covered with natural hardwood forests (Bones 1978). These forests may be managed for valuable hardwood lumber or converted to pine plantations for fiber production. Coal is another abundant natural resource in the state is frequently surface mined on forestry-based industrial lands.

Surface mines are recontoured soon after the mining operation is completed. The heterogenous artificial soils which cover the site are quickly regenerated with plants to prevent soil erosion. Herbaceous plants which are often used are legumes including vetch, clover, and Lespedeza and grasses (oats, fescue, and millet). These plants usually colonize and dominate the new sites very quickly, and the resulting plant competition inhibits the reestablishment of natural hardwood forests. Forestry operations on surface mined lands are greatly hampered due to the difficulty of forest regeneration, thus removing large acreages of forestry land from productivity for many years.

Numerous experimental trials of replanting hardwood and conifer species on reclaimed surfaces have been made. Black locust (Robinia pseudoacacia L.) has been demonstrated to be a successful, fast-growing hardwood when planted on these sites (Brown 1973). One of the most widely planted tree species in the world (Keresztesi 1980), it is a rapidly growing, shade-intolerant species which grows well on a range of soil qualities. The wood is naturally resistant to decay and resists swelling and contracting with moisture changes, and as a legume it improves soil quality by fixing atmospheric nitrogen. Black locust has been used in the forest industry as a source of railroad ties, fenceposts, mine timbers, stakes, boxes, and other items. Fencepost-sized trees can be grown in 15 to 20 years (Kellogg 1933). The wood has a high specific gravity of about 0.73 ovendry (Panshin and de Zeeuw 1970) and is one of the most efficient wood sources in the paper-pulping process.

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[1] Paper presented at the 1988 Mine Drainage and Surface Mine Reclamation Conference sponsored by the American Society for Surface Mining and Reclamation and the U.S. Department of the Interior (Bureau of Mines and Office of Surface Mining Reclamation and Enforcement) April 17-22, 1988, Pittsburgh, PA.

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The best growth of black locust has been found in West Virginia (Fowells 1965). Because of its extensive use on strip mined soils, a great opportunity exists to improve the surface mined land quality while concurrently producing wood for wood products by establishing plantings of black locust on these lands.

Most forest tree species exhibit genetic variation in height and volume growth. Considerable gain has been made in recent years by identifying superior sources of many tree species. Kennedy (1983) has reported genetic variation among sources of black locust in seed length, seed length/width ratio, seedling height, rachis length, and timing of spring bud break. Provenance tests of over 100 locust seedlots have been established in West Virginia since 1984. The purposes of these tests are to determine how much genetic variability exists in black locust and which sources are the most desirable for planting on surface mined land. Recommendations from field performance results of these tests will not be available for another 3 to 9 years. Physiological traits which may reflect expected field performance can be measured immediately, however. The basic photosynthetic pigments, chlorophyll A and chlorophyll B, can easily be measured in a laboratory using spectrophotometric techniques (MacKinney 1941). These chemicals are primary components of carbon assimilation, and variation in their concentrations may indicate limits in the amount of possible growth. Concentrations of the basic nutrients N, P, Ca, Mg, and K may also limit seedling development. Studies of these traits were made to provide genetic information in advance of useful growth data. Knowledge of the genetic variation in leaf physiology will lead to a better understanding of tree growth and of ways to improve the species.

PROCEDURES

Plantation Establishment

Seed collections were made throughout the range of black locust during the years 1981 to 1984. Three experimental plantations of seedlings on surface mined lands have been established in Greenbrier County, WV (table 1).

Greenhouse-grown seedlings were produced at Westvaco's West Virginia Research Center in Rupert, WV. The nursery-grown seedlings were produced at the Parsons, West Virginia State Nursery. Each planting is composed of five or six blocks within which all seedlots are represented and randomly distributed. Measurements of height and survival are made annually. Relative heights were expressed as a percentage of the plantation mean.

Plant materials for the physiological studies were obtained from the 1984 Bellburn planting. Table 2 lists geographic origins for each seedlot. Prior to the 1985 growing season, after one year in the field, the seedlings ranged in height from 6 to 120 cm.

Table 1.--Location, elevation, and establishment data of experimental black locust plantations, Greenbrier County, WV.

Site	Ele.	Year Estab.	No. of Seedlots	Seedling type
Bellburn #1	823 m	1984	30	Greenhouse-grown
Clearco	1070 m	1985	26	Greenhouse-grown
Bellburn #2	823 m	1986	117	Nursery-grown, 1-0 Stock

Chlorophyll Analysis

Two times during the 1985 growing season, on June 12 and August 23, leaf samples were collected on randomly selected, fully developed leaves to perform chlorophyll concentration analyses. A paper punch was used to make a 0.266 cm^2 leaf disk of each sampled leaf. Tissues were collected only on the leaflet blade, avoiding the midrib. Leaf disks were immediately stored in a glass vial which was transported to the lab inside an ice chest. All vials were stored in the freezer as soon as they were returned to Westvaco's West Virginia Research Laboratory. Chlorophyll analyses were similar to those described by Arnon (1949). Disks were homogenized in 3 ml of 80% acetone for 10 min. The mixture was transferred to graduated centrifuge tubes, diluted to 10 ml with 80% acetone, and centrifuged for 20 min at high speed. The supernatant was measured at 645 and 633 nm wavelength with a Beckman Spectronic 21 spectrophotometer using an 80% acetone blank (MacKinney 1941). Chlorophyll A (Chl. A) and chlorophyll B (Chl. B) concentrations were determined by the following equations:

$$\text{Chl. A (mg/L)} = 12.7\ D_{663} - 2.69\ D_{645}$$

$$\text{Chl. B (mg/L)} = 22.9\ D_{645} - 4.68\ D_{663}$$

$$\text{Total chlorophyll (mg/L)} = 20.2\ D_{645} + 8.02\ D_{663}$$

where D_{645} and D_{663} are the optical density readings at 645 and 663 nm, respectively. Concentrations in the extract solutions were adjusted for total area of leaf disks used in the extraction. Final leaf concentrations were given as $\mu g/cm^2$ leaf area.

Table 2.--Geographic origins of seedlots in the 1984 Bellburn #1 black locust seedlot test.

Seedlot	City	County	State	North Latitude		West Longitude		Elevation, m
683	Blacksburg	Pulaski	VA	37°	09'	80°	33'	536
687	Blacksburg	Montgomery	VA	37	17	80	27	689
688	Gay	Meriwether	GA	33	01	84	35	244
692	Gay	Meriwether	GA	32	58	84	41	259
696	Dadeville	Tallapoosa	AL	32	50	85	48	198
699	Dadeville	Tallapoosa	AL	32	50	85	48	201
700	Dadeville	Tallapoosa	AL	32	50	85	48	201
701	Grant	Marshall	AL	34	31	86	15	372
703	Gurley	Madison	AL	34	46	86	30	238
707	Hiawassee	Towns	GA	34	52	83	43	622
712	Hiawassee	Towns	GA	34	55	83	42	597
715	Lake City	Campbell	TN	36	17	84	12	372
716	Caryville	Campbell	TN	36	18	84	13	323
720	Staunton	Augusta	VA	38	05	79	05	469
722	Staunton	Augusta	VA	38	13	79	03	475
730	Umpire	Howard	AR	34	17	94	03	268
732	Umpire	Howard	AR	34	15	94	04	244
734	Licking	Texas	MO	37	34	91	53	366
742	Chestnut Mound	Smith	TN	36	13	85	50	213
743	Elmwood	Smith	TN	36	13	85	53	165
748	Robbinsville	Graham	NC	35	17	83	46	695
750	Bryson City	Swain	NC	35	25	83	28	543
754	Gneiss	Macon	NC	35	06	83	16	884
756	Gneiss	Macon	NC	35	08	83	17	645
797	Univ. Park	Centre	PA	40	48	75	55	384
799	Univ. Park	Centre	PA	40	49	77	56	421
808	Frostburg	Allegany	MD	39	39	78	59	640
811	Frostburg	Allegany	MD	39	37	78	52	488
812	Elkins	Randolph	WV	38	54	79	42	725
815	Harman	Randolph	WV	38	54	79	33	847

Nutrient Analysis

A collection of leaves was made on June 12, 1985, in order to perform a nutrient variation analysis. One fully mature leaf randomly selected from each of the five trees of a seedlot was collected within each block. If leaf samples were too small to make a minimum 1 g ovendry sample, additional leaves were collected from trees within the block. One hundred and seventy-five samples were collected, dried, and analyzed at the Westvaco Forest Science Laboratory for N, P, Ca, Mg, and K.

Simple correlations of seedlot mean values for nutrient and chlorophyll concentrations and height growth were made to determine possible patterns.

RESULTS

Seedlot Chlorophyll Variation

Chlorophyll A concentrations were consistently higher than chlorophyll B concentrations across all seedlots during both collection times. Chl. A comprised over 60 percent of total chlorophylls, and showed a slight increase in the August collection. Mean seedlot values in the June measurements ranged from 22 to 29 $\mu g/cm^2$ for chlorophyll A and from 13 to 19 $\mu g/cm^2$ for chlorophyll B (table 3). The range of August values was 21 to 35 and 13 to 21 $\mu g/cm^2$ for chlorophyll A and B, respectively. Significant seedlot differences in Chl. A concentrations existed in both the June and August measurements (table 4). Differences among seedlots for Chl. B were only observed in the August collection. The ratio between Chl. A and Chl. B did not vary between seedlots. This ratio was higher in the August collection, however, due to an increase in Chl. A levels.

For a specific collection period, the values of Chl. A, Chl. B and total chlorophylls were highly correlated. Seedlots number 699 from Alabama and 812 from West Virginia had the highest chlorophyll levels in the June collection. They still had high rankings in the August collection, but seedlot 815 from West Virginia, which had a much lower level in the June collection, had the highest August levels. Seedlot 799 decreased in total chlorophyll from the June to August collections. Analysis of variance indicated no interaction between seedlot and date of collection (table 4). The ratio between Chl. A and Chl. B showed no consistent relationship across seedlots in both collections.

There was no apparent geographic pattern to the chlorophyll measurement variation. The highest June values were in

Table 3.--Concentrations of chlorophylls and the ratio of chlorophyll A to chlorophyll B in the leaves of thirty black locust seedlots.

	Chlorophyll A			Chlorophyll B			Total Chlorophyll			Chl. A/Chl. B Ratio		
Seedlot	June	August	Avg.	June	August	Avg.	June	August	Avg.	June	August	Avg.
	- µg/cm² -											
683	25a-e*	24b-e	25b-h	15	14b	15cd	41a-d	38cde	40b-h	1.65	1.67	1.66
687	22e	23cde	22h	14	14b	14d	36d	37cde	36gh	1.55	1.61	1.58
688	23b-e	21de	22h	15	13b	14d	38bcd	34de	36h	1.55	1.59	1.57
692	22de	29a-d	26b-h	14	18ab	16bcd	36cd	47a-e	41b-h	1.59	1.68	1.63
696	27a-d	29a-e	28a-d	17	17ab	17abc	44abc	46a-e	45a-d	1.60	1.64	1.62
699	29a	33ab	31a	19	20a	19a	48a	53ab	51a	1.59	1.61	1.60
700	25a-e	29a-e	27a-g	15	18ab	16bcd	39a-d	46a-e	43b-h	1.67	1.64	1.65
701	26a-e	23cde	25b-h	16	14b	15bcd	42a-d	38cde	40b-h	1.66	1.64	1.65
703	24a-e	24b-e	24c-h	16	14b	15bcd	40a-d	39cde	39b-h	1.56	1.68	1.62
707	25a-e	22cde	24d-h	16	14b	15bcd	41a-d	36cde	39c-h	1.57	1.65	1.60
712	23b-e	22cde	23fgh	14	13b	14d	38bcd	36cde	37fgh	1.64	1.67	1.66
715	24a-e	26a-e	25b-h	15	15b	15bcd	39a-d	41b-e	40b-h	1.61	1.70	1.66
716	26a-e	22cde	24d-h	16	14b	15bcd	42a-d	36cde	39b-h	1.60	1.58	1.59
720	23b-e	25b-e	24d-h	14	15b	15cd	36cd	40b-e	38d-h	1.63	1.64	1.63
722	24a-e	27a-e	25b-h	15	16ab	15bcd	39bcd	42a-e	40b-h	1.65	1.70	1.67
730	26a-e	29a-e	27a-f	16	17ab	17bcd	41a-d	46a-e	44a-g	1.64	1.69	1.67
732	25a-e	28a-e	26b-h	16	18ab	16bcd	40a-d	45a-e	42b-h	1.57	1.57	1.57
734	23b-e	22cde	22h	14	13b	14d	37bcd	35cde	36h	1.58	1.64	1.61
742	23b-e	24b-e	23d-h	15	13b	14d	38bcd	37cde	38e-h	1.57	1.75	1.66
743	25a-e	30abc	27a-g	16	18ab	17abc	41a-d	48abc	44a-f	1.54	1.65	1.59
748	24a-e	27a-e	26b-h	16	15ab	15bcd	40a-d	42a-e	41b-h	1.57	1.71	1.65
750	26a-e	26a-e	26b-h	15	16ab	15bcd	41a-d	41b-h	41b-h	1.67	1.67	1.67
754	23b-e	22cde	23gh	14	13b	14d	37bcd	35cde	36h	1.62	1.70	1.66
756	22de	25b-e	23d-h	14	15ab	15cd	36cd	41b-e	38d-h	1.55	1.63	1.58
797	22cde	29a-d	26b-h	13	18ab	16bcd	35d	47a-e	42b-h	1.68	1.63	1.65
799	26a-e	20e	23e-h	16	13b	15cd	42a-d	33e	38e-h	1.62	1.56	1.59
808	28ab	27a-e	27a-f	16	17ab	17bcd	44a-d	44a-e	44a-g	1.69	1.59	1.64
811	28abc	31abc	29ab	16	18ab	17abc	44a-d	49abc	46abc	1.70	1.70	1.70
812	28ab	30a-d	29abc	18	18ab	18ab	46ab	48a-d	47ab	1.59	1.67	1.63
815	23b-e	35a	28a-e	15	21a	17abc	38bcd	55a	45a-e	1.57	1.70	1.62
Overall	25	26	25	15	16	16	40	42	41	1.61	1.65	1.63

*Values within a column followed by the same letter are not significantly different at 5% by Duncan's Multiple Range Test.

seedlots from Alabama, West Virginia, and Maryland. The lowest June values were seedlots from Virginia, Georgia, North Carolina, and Pennsylvania. The August values similarly indicated no geographic patterning to the variation.

The lack of a clear-cut geographic pattern to the variation is significant because most tree species do show such variation. It is possible that natural variation has been severely disturbed by artificial regeneration techniques during the past several hundred years.

Leaf Nutrient Variation

Leaf nutrient levels also varied between seedlots. Of the five nutrients routinely analyzed, only calcium showed no seedlot source differences (table 5). Significant block differences for N and Ca levels may have been due to the artificial mixing of soils associated with strip mining.

Correlation analysis of individual samples indicates that nitrogen levels were proportional to phosphorus, calcium, and potassium levels. Phosphorus levels also correlated positively with magnesium and potassium. Although seedlot differences were significant for four nutrients, the ranges of values were not great (table 6). Seedlot 688 from Meriwether County, GA, had the highest values for most nutrients. Seedlot 815 from Randolph County, WV, had the lowest nitrogen levels. As with the chlorophyll variation, no geographic patterns could be determined among the seedlots.

Height Growth Variation

The most recent data are presented in table 7 for 56 seedlots. Statistically distinct differences in growth can be seen in each study. At the Bellburn #1 location, seedlots from Tennessee, Alabama, and West Virginia had the best growth by age 3 yrs. In the Clearco study, lot BN4194, Table 4.--Analysis of variance of black locust leaf chlorophyll concentrations.

		Chlorophyll A		Chlorophyll B		Chl. A/Chl. B	
Source	DF	Type III Sums of Squares	F	Type III Sums of Squares	F	Type III Sums of Squares	F
Spring Collection							
Seedlot	29	682.45	1.70 *	232.38	1.34 NS	0.3450	0.98 NS
Block	5	200.32	2.90 *	84.13	2.81 *	0.1608	2.65 *
Error	136	1879.02	-	814.81	-	1.6482	-
Fall Collection							
Seedlot	29	2015.60	1.85 *	725.91	2.21 **	0.3307	1.05 NS
Block	5	413.69	2.20 NS	80.68	1.37 NS	0.2822	5.21 **
Error	127	4782.61	-	1498.85	-	1.3757	-
Combined Measurements							
Seedlot	29	1811.19	2.13 **	671.50	2.32 **	0.4135	1.16 NS
Block	5	138.39	1.17 NS	26.73	0.65 NS	0.1079	1.70 NS
Error A	140	4109.91	1.25 NS	1398.32	1.21 NS	1.7195	0.97 NS
Collection	1	115.16	4.88 *	6.76	0.82 NS	0.1132	8.94 **
S X C	29	941.14	1.38 NS	333.38	1.39 NS	0.3194	0.87 NS
Error B	128	3017.97	-	1057.76	-	1.6212	-

*, ** - Differences between means are significant at 5% and 1%, respectively.
NS - No significant differences between means.

Table 5.--Statistical analysis of variance of black locust seedlot leaf nutrient levels.

	Source		
Degrees of Freedom	Seedlot 29	Block 5	Error 140
Nitrogen			
Type III Sum of Squares	5.64	1.23	14.95
F	1.82*	2.32*	-
Phosphorus			
Type III Sum of Squares	0.06	0.01	0.12
F	2.23**	1.29NS	-
Calcium			
Type III Sum of Squares	0.43	0.28	1.68
F	1.24NS	4.58**	-
Magnesium			
Type III Sum of Squares	0.13	0.01	0.26
F	2.39**	1.56NS	-
Potassium			
Type III Sum of Squares	2.15	0.06	4.11
F	2.53**	0.43NS	-

* - Differences significant at 5%.
** - Differences significant at 1%.
NS - Differences not significant.

which was provided by the Soil Conservation Service, but originated in West Virginia, performed excellently. The Bellburn #2 study showed additional good material from Virginia. Seedlot # 716 from Tennessee performed well in both of the Bellburn plantings. Individual tree selection is necessary for an efficient genetic improvement program.

Although seedlot differences exist, we have not observed any geographic pattern from which we can make collection recommendations. This observation is consistent with those made by other researchers who have concluded that little geographic variation can be associated with genetic variation in black locust (Bongarten 1985; Kennedy 1983). Individual tree selection is necessary for an efficient genetic improvement program.

Relationship Between Traits

Mean seedlot values for each trait measured in this report were compared to determine possible relationships which may exist. Although considerable variation occurred in the data, simple linear regressions did point out some expected and unexpected relationships.

Seedlots with higher levels of nitrogen tended to have higher phosphorus ($r = 0.54$) and potassium levels ($r = 0.37$). Phosphorus levels also paralleled magnesium levels. The results are similar to those observed with individual sample correlations. An unexpected result was the negative relationship between certain nutrients and chlorophyll concentrations and height

Table 6.--Leaf nutrient variation among thirty seedlots of black locust seedlings.

Seedlot	Nitrogen	Phosphorus	Calcium	Magnesium	Potassium
	-% Tissue-				
683	3.15 a-e	0.21 a-e	0.58	0.24 cde	1.62 b-e
687	2.80 de	0.19 cde	0.51	0.22 cde	1.52 cde
688	3.48 a	0.25 a	0.62	0.30 ab	1.96 a
692	3.04 a-e	0.19 cde	0.46	0.21 e	1.80 ab
696	3.26 a-d	0.19 cde	0.50	0.19 e	1.57 b-e
699	3.36 ab	0.20 cde	0.53	0.20 e	1.67 bcd
700	2.99 b-e	0.18 de	0.58	0.21 de	1.59 b-e
701	3.07 a-e	0.18 de	0.49	0.21 e	1.64 bcd
703	3.03 a-e	0.19 cde	0.53	0.24 a-e	1.62 b-e
707	3.24 a-d	0.21 a-e	0.57	0.19 e	1.64 bcd
712	3.06 a-e	0.20 b-e	0.46	0.20 e	1.57 b-e
715	3.15 a-e	0.19 de	0.59	0.22 cde	1.76 abc
716	3.07 a-e	0.17 e	0.51	0.20 e	1.68 bcd
720	3.14 a-e	0.19 de	0.48	0.21 e	1.67 bcd
722	3.36 ab	0.22 a-d	0.53	0.27 a-d	1.50 de
730	3.01 a-e	0.21 a-e	0.51	0.20 e	1.72 bcd
732	3.19 a-e	0.21 a-e	0.50	0.19 e	1.56 b-e
734	3.25 a-d	0.24 ab	0.55	0.30 a	1.51 cde
742	3.19 a-e	0.18 de	0.58	0.25 a-e	1.65 bcd
743	3.34 ab	0.20 cde	0.59	0.22 de	1.63 bcd
748	2.82 cde	0.20 cde	0.59	0.22 de	1.43 de
750	3.16 a-e	0.22 a-d	0.48	0.24 a-e	1.53 cde
754	3.12 a-e	0.23 abc	0.53	0.28 abc	1.64 bcd
756	3.38 ab	0.23 abc	0.50	0.22 cde	1.62 bcd
797	3.28 abc	0.21 a-e	0.57	0.24 b-e	1.69 bcd
799	2.99 b-e	0.19 de	0.59	0.21 de	1.38 e
808	3.20 a-d	0.21 a-e	0.63	0.23 cde	1.55 cde
811	3.07 a-e	0.21 a-e	0.60	0.22 de	1.73 bcd
812	2.86 cde	0.19 cde	0.56	0.22 cde	1.64 bcd
815	2.72 e	0.18 de	0.62	0.24 a-e	1.49 de
Mean	3.12	0.20	0.54	0.22	1.62

* Values within a column followed by a common letter are not significantly different at 5% by Duncan's Multiple Range Test.

growth. Seedlot values for magnesium tended to decrease with increasing chlorophyll levels. Height increments were negatively related to phosphorus (r = -.60) and magnesium levels (r = -.68).

The various chlorophyll measurements tended to show positive relationships between seedlots, as could be expected. They also exhibited a positive relationship with height growth. The June measurements were more strongly related to overall seasonal growth than August levels. This relationship is supported by the variation in June foliage coloration. Seedlots which had the highest total chlorophyll in June generally had greater growth rates during the season (fig. 1). Some seedlots may produce chlorophyll earlier in the season which may allow some growth advantage. This possible relationship between June chlorophyll levels and overall seasonal growth should be verified as it may be a useful selection tool.

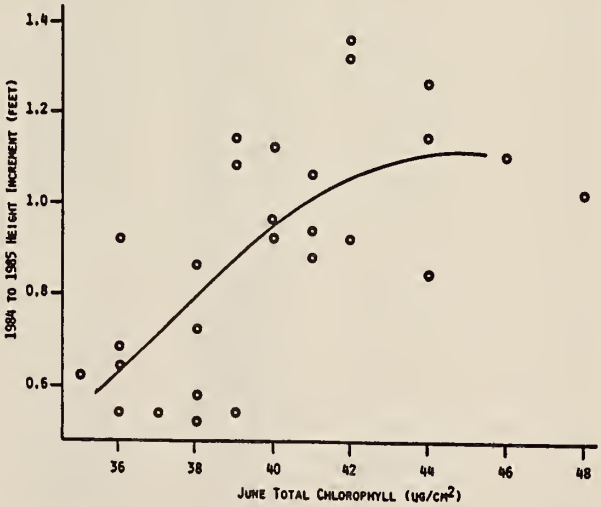

Figure 1.--Distribution of seedlot mean values for total June chlorophyll and height increment during the 1985 Growing season. The curvilinear regression accounts for 50% of the variation.

Table 7.--Relative heights of 56 black locust seedlots planted on 3 sites in West Virginia. Seedlots within a planting site which are followed by a common letter are not significantly different at a 95% probability.

Seedlot	Bellburn #1 3 yr old	Clearco 2 yr old	Bellburn #2* 1 yr old
	-Relative Heights and Differences- Percent of Plantation Mean		
683	89 A-E	--- ---	106 B-Q
687	81 CDE	--- ---	130 A-D
688	92 A-E	--- ---	94 E-X
692	83 B-E	--- ---	109 A-O
696	115 A-D	--- ---	87 J-X
699	106 A-E	--- ---	--- ---
700	113 A-D	--- ---	100 C-S
701	121 AB	--- ---	71 R-Y
703	103 A-E	--- ---	124 A-F
707	99 A-E	--- ---	100 C-S
712	103 A-E	--- ---	106 B-Q
715	105 A-E	--- ---	103 B-S
716	125 A	--- ---	134 AB
720	79 DE	--- ---	95 E-W
722	79 DE	--- ---	92 E-X
730	105 A-E	--- ---	111 A-N
732	95 A-E	--- ---	84 K-X
734	71 E	--- ---	--- ---
742	109 A-D	--- ---	--- ---
743	103 A-E	--- ---	112 A-N
748	105 A-E	--- ---	63 T-Y
750	85 B-E	--- ---	93 E-X
754	83 CDE	--- ---	90 F-X
756	92 A-E	--- ---	98 D-S
797	100 A-E	--- ---	105 B-R
799	95 A-E	--- ---	125 A-D
808	95 A-E	--- ---	111 A-N
811	113 A-D	--- ---	107 B-Q
812	117 ABC	--- ---	106 B-Q
815	100 A-E	--- ---	102 B-S
838	--- ---	93 CDE	60 XY
839	--- ---	112 BCD	112 A-M
840	--- ---	80 DEF	85 K-X
841	--- ---	92 C-F	89 G-X
842	--- ---	90 C-F	73 Q-Y
845	--- ---	98 CDE	114 A-L
846	--- ---	98 CDE	84 K-X
847	--- ---	122 BC	93 E-X
848	--- ---	79 DEF	113 A-L
849	--- ---	101 CDE	95 E-W
852	--- ---	56 F	--- ---
856	--- ---	71 EF	--- ---
857	--- ---	85 C-F	--- ---
858	--- ---	115 BCD	--- ---
860	--- ---	83 DEF	120 A-I
861	--- ---	111 BCD	119 A-I
862	--- ---	72 EF	96 D-U
863	--- ---	83 DEF	88 H-X
865	--- ---	93 CDE	97 D-T
866	--- ---	81 DEF	62 WXY
867	--- ---	96 CDE	100 C-S
868	--- ---	92 C-F	78 N-Y
869	--- ---	85 C-F	108 A-O
4191	--- ---	138 AB	--- ---
4192	--- ---	101 CDE	--- ---
4194	--- ---	157 A	--- ---

*Only those seedlots common to the other plantings are listed.

CONCLUSIONS

This research in black locust seedlot variations has led to the following conclusions:

1. The concentrations of chlorophylls A and B in the leaves of black locust seedlings vary seasonally, increasing from low June levels to the highest levels in August.
2. Concentrations of chlorophylls in black locust exhibit considerable seedlot variation. The variation has no geographic patterning associated with it. Chlorophyll A had a consistently higher concentration than chlorophyll B and increased in concentration during the season.
3. There are no significant interactions between seedlot chlorophyll levels and time of collection.
4. The ratio between chlorophyll A and chlorophyll B did not vary between seedlots. It did increase during the growing season as chlorophyll A levels increased and chlorophyll B did not.
5. Leaf nutrient levels of N, P, Mg, and K did vary significantly between seedlots. No geographic patterning was associated with this variation.
6. Simple correlation analysis of the various traits measured indicates a positive relationship between June chlorophyll levels and overall seasonal growth. Seedlot variation in the rates of chlorophyll development may yield a growth advantage and possibly could be used as a selection criterion in black locust improvement.
7. Seedlots do vary significantly in their rate of growth. Several seedlots have been identified which are superior to others when planted on surface mined lands. As the technology to reproduce superior black locust genotypes develops, owners of reclaimed surface mines may be able to select and plant only the best material for their sites.

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ESTABLISHMENT OF TREES IN HERBACEOUS COVER ON GRADED LENZBURG MINESOIL[1]

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Abstract.--The effects of a developing herbaceous cover on tree survival and growth, with and without herbicides, were evaluated on graded, fertilized, remined boxcut spoil in southern Illinois. A pasture mix of tall fescue (Festuca arundinacea Schreb., selection Ky-31), orchardgrass (Dactylis glomerata L., selection Potomac), and alfalfa (Medicago sativa L., selections Arc and Kansas) was sown in the fall 1980 and spring 1981. The herbaceous cover was poorly established in 1981 and well established in 1986. Tree seed of green ash (Fraxinus pennsylvanica Marsh.), black walnut (Juglans nigra L.), and northern red oak (Quercus rubra L.) were planted in fall of 1980 and 1981, and tree seedlings of the same species were planted in spring of 1981 and 1982. Half of the 5,760 tree planting spots were herbicided with Roundup and Princep early in the first growing season after each planting. Survival and growth measurements in 1986 showed slightly better survival of non-herbicided green ash, better survival of hercided black walnut and red oak, and better growth of herbicided trees in all experimental groupings. Survival and growth of trees planted the same season as the herbaceous cover (6-year-old trees) were higher than of trees planted in year-old herbaceous cover (5-year-old trees), except for survival of black walnut from seed. Both tree survival and growth were relatively low on the graded minesoil with herbaceous competition.

INTRODUCTION

Successful reclamation typically includes a revegetation component, be it row crop, pasture, forest, or other land uses. How reclamation is carried out is regulated by State and Federal Agencies. Applicable regulations include grading and establishment of a ground cover for erosion control. Soil compaction associated with site grading in the midwest typically increases the need for erosion control because of decreased rates of water infiltration and increased rates of runoff.

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Tree planting was often the only type of reclamation prior to the Surface Mining Control and Reclamation Act of 1977 (PL 95-87), with millions of trees successfully planted (Ashby et al. 1978). Ground cover was rarely used and tree seedlings commonly established and grew well. Less success has attended many post-law tree plantings, leading to widespread concern among reclamation personnel that today's emphasis on ground cover limits tree survival and growth.

Because of their vigor, available seed, and widespread use, pasture grasses and legumes are commonly used for ground cover in reclamation plantings. These species are especially detrimental to survival and growth of trees. Our study focused on testing whether trees of green ash, black walnut, or red oak planted initially with pasture species would be more successful than those planted later in developing herbaceous cover. Other studies are being carried out to find those herbaceous species which are especially effective for erosion control and which do not compete excessively with tree seedlings.

MATERIALS AND METHODS

This study was carried out on spoil that had been remined in the late 1970's by Freeman United Coal Mining Company's Fidelity Mine in southern Illinois. Cast overburden from a boxcut was graded to a mound about 1.5-km (1-mile) long with a minimal, but still substantial amount of grading. Minesoil bulk densities measured on the study site ranged from 1.60 to 1.90 g/cm^3 (Norland 1982). The rooting medium has been classified as Lenzburg gravelly silty clay loam with an average 15% north-facing slope. Minesoil samples generally had a pH above 7.0 with occasional acidic "hot spots". Available phosphorus (Bray P_1) and potassium tested very low, and reserve phosphorus (Bray P_2) high. Plant foliar analyses showed only P to be deficient.

In August-September 1980 a section of this mound was broadcast fertilized with 112 kg/ha (100 lb/A) each of ammonium nitrate and triple super phosphate and sown with 0.2 hectoliters/ha (1.5 bushel/A) oats (Avena sativa L.) as cover crop, and with a pasture mix of inoculated Arc alfalfa (11.2 kg/ha or 10 lb/A), Ky-31 tall fescue (11.2 kg/ha), and Potomac orchardgrass (4.5 kg/ha) in accordance with provisions of the federal surface mining act. Because of poor establishment during a continuing severe drought in 1980, the area was resown with each species at half-rate in March 1981. Kansas rather than Arc alfalfa was used in the spring.

A 4-ha (10-acre) study site planted to ground cover was divided into 40 tenth-ha (quarter-acre) plots and planted to a total of 5,760 trees in the same seasons as the pasture species, either concurrently or 1 year later. Each plot had 12 rows of 12 trees each on a 2.5-m (8.2-ft.) spacing with one-fourth of the green ash, red oak and black walnut rows planted successively in fall 1980, spring 1981, fall 1981, and spring 1982. Rows were completely randomized per plot. Recently-collected seed of all species was planted in the fall, and seedlings in the spring. Multiple seed per spot were planted based on expected germination percentages.

In the early spring of the first growing season after planting a mixture, 1.5% each of Roundup (9.4 l/ha with 41% active ingredient [a. i.] glyphosate) and Princep (5.6 kg/ha with 80% a. i. simazine) herbicides, was sprayed on the developing ground cover in a 1.5-m circle around half of the trees. Use of trade names does not constitute endorsement of these products. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

Adjacent columns of plots were combined to give 20 paired plots with 24 rows each, and rows of each tree species in the 20 paired plots were randomly selected for spraying. Thus, half of the fall 1980/spring 1981 plantings were herbicided in 1981, and half of the fall 1981/spring 1982 plantings in 1982. Survival counts were taken in 1981, 1982, 1983, and 1986. Height measurements were made in 1986.

Our research objective was to evaluate survival and growth of trees planted in a developing cover of highly competitive herbaceous species. Three specific research questions were:

A. Do tree species successively planted in a developing herbaceous cover differ in their survival and growth?

B. Is establishment, survival, and growth of trees influenced by the use of herbicide?

C. Do trees planted in the fall as seed, or in the spring as seedlings, have better survival and growth?

This study utilized a randomized complete block design. The experimental unit for survival was a planting spot, and for height was a planting row of 12 planting spots. If few trees survived, numerous planting rows with zero height resulted in a mean height lower than the median value for trees of that experimental grouping.

Statistics were calculated by computer using the SAS (Statistical Analysis System) and the PROC GLM (general linear model procedure) to determine significant ($\alpha = 0.01$) differences in a three-way analysis of variance. Differences between species, treatment, and planting type/season along with main effect interactions were tested.

RESULTS

Establishment of the pasture species was good. After 6 growing seasons tall fescue was recorded in 98% of the tree rows, alfalfa in 85% and orchardgrass in 3%. Although the herbicide treatments were relatively effective and still evident as bare or thinly vegetated circles for numerous seedling- or seed-spots in 1986 after either 6 or 5 tree-growing seasons, herbaceous competition likely still affected the tree seedlings even in the herbicided rows. An indirect effect was that in 1984 a tremendous vole/field mouse population in the herbaceous cover girdled nearly all red oak, stripped bark on the green ash, and chewed the bark on many walnut. The high point of vole population density coincided with a severe growing-season drought period that likely exacerbated the tree damage from voles as the herbaceous vegetation dried up. Growth measurements were not made in 1984 because for many seedlings it was not possible to tell whether they were still alive or not.

Scattered deer browsing was observed on several occasions. Drought effects on the trees and herbaceous cover had also been evident in 1983. Related to these several factors basal sprouting and/or tip dieback were common for all species in all groupings.

Number of surviving trees and mean row height showed significant differences for species, planting method/season, and for their interaction for all ages of trees planted concurrently with, or one year later than the herbaceous cover pasture mix (tables 1 and 2). Herbicide treatment effects in year 6 and year 5 were significant under all treatments except for tree survival when planted later than the pasture mix (table 2). Interaction effects involving herbicide treatment were minor. The apparently inhibitory effects of herbicides on green ash affected the analysis of variance.

Trees from seedling (versus seed) origin had higher survival and mean row heights, as did those herbicided versus non-herbicided (table 1). Green ash had greater survival and mean row height than black walnut or red oak when planted either concurrenly with a pasture mix or 1 year later. Black walnut outperformed red oak when planted in year-old herbaceous cover.

Including Norland's (1982) data from years 1, 2, and 3 it is evident that the number of surviving trees of all species, treatments, and plantings decreased with age under both planting schedules (table 3). The relative decrease in numbers from year 1 to year 6 or 5 was greatest for green ash and red oak seed, and black walnut seedlings. Green ash established and survived less well from seed than the other two species. Fewer green ash survived when herbicided, in contrast to black walnut and red oak. The number of surviving black walnut was greater from seed than seedlings.

DISCUSSION

This study included state-of-the-art reclamation practices as well as utilizing a site reclaimed under the then-applicable State and Federal regulations. Our choice

Table 1.--Percent survival and mean row height after planting for populations of green ash, black walnut, and red oak planted concurrently with a pasture mix or 1 year later.

	Survival				Mean Row Height[1]			
	Pl. Conc. (Year 6)		Pl. Later (Year 5)		Pl. Conc. (Year 6)		Pl. Later (Year 5)	
Grouping	%	%	%	%	cm	cm	cm	cm
A Species	20.8		10.0		29.4		17.5	
Green ash		35.8		16.7		40.9		26.1
Black walnut		11.7		10.8		25.1		21.0
Red oak		14.2		2.5		22.2		5.5
B Treatment	20.8		10.0		29.4		17.5	
Non-herbicide		17.5		9.2		21.3		11.8
Herbicide		24.2		11.7		37.4		23.2
C Planting	20.8		10.0		29.4		17.5	
Seed/Fall		6.7		6.7		16.2		11.7
Seedling/Spring		34.2		13.3		42.6		23.3

[1] Mean heights on a per-tree basis for green ash, black walnut and red oak respectively were for year 6--82.5, 51.1, and 39.1 cm; and for year 5, with lower survival--56.6, 61.1, and 22.2 cm.

Table 2.--Analysis of variance ($\alpha = 0.01$) for survival and mean row height 1, 2, or 6, and 1 or 5 years after planting for populations of green ash, black walnut, and red oak planted either concurrently with a pasture mix or 1 year later.[1] Treatment was herbicide and non-herbicide. Planting was seed/fall and seedling/spring.

	Number of Surviving Trees					Height	
	Planted Concurrently			Planted Later		Pl. Conc.	Pl. Later
Grouping	Year 1	Year 2	Year 6	Year 1	Year 5	Year 6	Year 5
A Species	*	*	*	*	*	*	*
B Treatment	-	-	*	*	-	*	*
C Planting	*	*	*	*	*	*	*
AB	-	-	*	*	-	-	-
AC	*	*	*	*	*	*	*
BC	-	-	-	*	-	-	-

[1] Data for years 1 and 2 from Norland (1982).

Table 3.--Percent survival and mean row height 1, 2, 3, or 6 and 1, 2, or 5 years after planting for populations of green ash, black walnut, and red oak planted either concurrently with a pasture mix or 1 year later.[1] Seed was fall- and seedlings spring-planted.

		Survival							Height	
		Planted Concurrently				Planted Later			Pl. Conc.	Pl. Later
		Year 1	Year 2	Year 3	Year 6	Year 1	Year 2	Year 5	Year 6	Year 5
Planting	Treatment	%	%	%	%	%	%	%	cm	cm
					Green ash[2]					
Seed	Non-herb.	3.4	0.8	0.0	0.0	22.1	0.8	0.0	0.0	0.0
	Herbicide	4.9	0.8	0.4	0.4	5.8	0.4	0.0	4.2	0.0
Seedling	Non-herb.	96.3	94.2	92.1	75.4	63.8	52.5	36.2	66.2	41.7
	Herbicide	94.5	92.1	89.6	68.8	63.8	63.3	31.2	93.4	62.6
					Black walnut					
Seed	Non-herb.	64.2	40.4	30.8	8.8	53.3	44.2	12.5	20.0	19.0
	Herbicide	70.0	39.6	36.7	21.7	77.1	75.4	22.1	46.8	39.4
Seedling	Non-herb.	91.3	48.3	24.6	2.1	60.8	11.7	1.7	8.1	4.2
	Herbicide	93.6	55.0	38.8	15.0	89.2	46.2	7.1	25.5	21.6
					Red oak					
Seed	Non-herb.	99.6	91.6	42.1	2.9	62.1	24.6	2.1	9.7	4.2
	Herbicide	96.0	86.9	53.8	7.9	79.6	40.4	2.9	16.4	7.8
Seedling	Non-herb.	89.9	68.8	45.8	16.2	60.4	11.2	0.8	24.0	1.9
	Herbicide	89.6	80.4	64.6	29.6	90.4	40.4	5.0	38.4	8.2

[1] Data for year 1, and year 2 planted concurrently, from Norland (1982).
[2] Green ash had 3 seed per seed spot in Fall 1980 and 12 seed per seed spot in Fall 1981. Black walnut and red oak had 3 seed per seed spot both seasons.

of the herbaceous cover pasture mix was based on current industry practice and on research by Grandt and Lang (1958) and others.

Our choice of tree species was based on experience and on review of a relatively extensive reclamation reforestation literature (Ashby et al. 1978, Vogel 1981). Further guidelines were earlier results from direct seeding (Kolar et al. 1981, Philo et al. 1981), expected deleterious effects of herbaceous cover on trees (Vogel 1980), and availability of methods for weed control (Parr 1982, Philo et al. 1983). We expected tree survival and growth to be limited by other possible adverse features of the mine site such as compaction (Limstrom 1960, Philo et al. 1982). Limitations from allelopathy were not specifically known.

We have observed similar good relative success of tall fescue and alfalfa and poor success of orchardgrass at several mine sites in southern Illinois, and conspicuous mortality of tree seedlings in dense tall fescue or alfalfa cover. When reforestation is a primary objective, less competitive herbaceous species would be desirable.

Specific identification of other possible limiting factors has not been feasible. Severe drought periods in 1983 and 1984, and the vole irruption in 1984 likely were of importance. The severe damage by voles in dense herbaceous cover of our study coincided with industry-wide losses of Illinois and Indiana tree plantings in the same year. A low-growing herbaceous cover would probably be better than tall fescue or alfalfa to increase visibility for predators of voles and other rodents that damage tree seedlings.

Our findings that even a 1-year-old herbaceous cover limits tree survival and growth reinforce Vogel's (1980) recommendation to plant trees at the same time or before the herbaceous species, if the latter have to be used. The numerous excuses to delay tree planting--seedlings not available, planting crews busy, current budget problems--need to be balanced against the greatly increased likelihood of planting failures. Acceptance of the generally favorable effects of herbicides has been reinforced by the results of this study. The effects of herbicide treatment evidently persisted longer than usually reported, with both favorable effects for black walnut and red oak, and the adverse effects for green ash, becoming more evident with time from year 1 to year 6 or 5. One hypothesis is that simazine as a pre-emergence herbicide had greatest effects on survival when trees and herbaceous cover were planted concurrently, and glyphosate as a contact herbicide had greatest effects on survival for trees planted 1 year later within an established herbacous cover. The need for further guidelines on use of herbaceous cover and for use of herbicides when growing trees has been demonstrated.

Our findings also support earlier reports of poor success in planting small-seeded species (ash) from seed (black locust [Robinia pseudoacacia L.] would be a bold exception), and of much better success with large-seeded trees (black walnut, which has been widely studied, and red oak). An ability of fall-seeded black walnut to outgrow seedlings became evident with a developing herbaceous cover. Philo et al. (1981) reported that controlling dense herbaceous vegetation with either herbicides or cultivation has given marked improvement in the survival of direct-seeded black walnut.

Seedlings were clearly superior in establishment and survival of green ash. Although poor ash germination/establishment could be attributed to poor seed, the dying off the trees which did establish from seed was unexpected. Sensitivity of ash to herbicide, or allelopathy, could have been a factor in early mortality from seed. Green ash from fall-planted seed is not recommended for reclamation plantings, and careful attention should be given to possible herbicide damage in use of ash seedlings under present reclamation practices. Green ash had lower percent year 1 survival than red oak or black walnut when machine-planted on graded sites with weed control (Parr 1982). Raisanen (1982), with similar overall survival had higher survival of all three species when herbicided.

An interpretation of the red oak survival data, and to a lesser extent the growth data, is that seedlings planted in the spring with a pasture mix had enough head start to attain more than twice the survival and growth of the plants from seed and seedlings planted a year later. Differential effects of voles in 1984 within the seriously affected red oak population were not observed. A relatively bare circle around the herbicided trees may have inhibited vole activity somewhat.

SUMMARY AND CONCLUSIONS

Herbaceous cover adversely affected establishment and later survival and growth of trees in reclamation. These effects were partially offset by planting trees early relative to the herbaceous cover, and by using herbicides to create a bare area around each tree seedling. Caution is needed in using herbicides with green ash.

Fall seeded green ash is not recommended. Green ash seedlings outperformed black walnut and red oak either when planted concurrently with herbaceous cover, or when planted in 1-year-old herbaceous cover.

The best red oak performance 5-6 years after planting was from seedlings planted with the herbaceous cover, especially with use of herbicides. By years 5 and 6 black walnut performed best with fall-planted seed. Walnut from seed performed equally well when planted concurrently with herbaceous cover or in year-old herbaceous cover. Herbicide application increased walnut survival and height growth. Based on this study, if other site conditions are favorable the best choices for reclamation tree plantings in established herbaceous cover would be fall planting of black walnut seed, and spring planting of green ash seedlings, with as much control of herbaceous cover as possible.

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SOIL DEVELOPMENT UNDER 22-YEAR-OLD MIXED HARDWOOD, PINE, AND BLACK LOCUST PLANTATIONS ON A SURFACE MINE

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Abstract.--A study of soil development under three forest vegetation types showed development of O, A, and B horizons after 22 years. O horizon thickness was significantly greatest under pine (3.5 cm) and least under mixed hardwoods (2.4 cm). O horizon concentrations of N, P, Ca, Mg, Cu, Zn, Si, and Ni had significant differences attributable to vegetation type. A horizon development was quite variable with a mean thickness of 2.3 cm. There were significant differences between the A and B horizons for organic matter content, conductivity, exchangeable acidity, and concentrations of available N, P, K, Ca, Mg, Mn, Cu, Zn, B, Na, Pb, Ti, and Cr. The differences for A and B horizons were not significant for pH, Fe, Si, Al, exchangeable Al, Co, or Ni. There were significant differences among vegetation types for the ratio of A to B horizon means for pH, exchangeable acidity, conductivity, N, Zn, B, Na, and Ni.

INTRODUCTION

Surface mining for coal in the Eastern United States causes disruption of soil horizon organization, as well as dispersal and sometimes loss of the original soil materials. Overburden materials which often were the parent materials for the original soils are frequently mixed and left at the surface of the reformed topography where they become the parent materials of future soils. Soils that develop on the mined site are a function of the climate, vegetation and other organisms, topography, parent material, and time (Jenny 1941). Of these variables, time is the only one that is independent of man's influence. Methods of mining, spoil movement, and placement determine the future soils' parent material. Topography influences soil hydrology and somewhat modifies effects of climate. The pioneer vegetation can have an influence lasting decades. In this paper we will examine the development of soils and the influence of vegetation under 22-year-old tree plantations on a surface mine in southeastern Kentucky.

METHODS

The Site

The study site is located near the community of Fonde in southwestern Bell County in southeastern Kentucky. The area was mined in 1959 and remined in 1963. The mine was a bench cut at 564 m elevation with highwall, bench, and outslope spoil deposits that were common at that time. The Kentucky Strip Mine Research Coordinating Committee[2] established an 18-acre demonstration area on the site in 1965 to show effects of some of the then-accepted methods of water control and revegetation. The bench was graded to direct surface waters toward the highwall, and two settling ponds with spillways were constructed. Acid-forming coal wastes and shales were buried where possible. Trees, shrubs, and grasses were planted on parts of the area. The USDA Soil Conservation Service designed and supervised construction of water control structures; American Association Limited supplied earth-moving equipment; the State-Federal Welfare, Education, and Training Program provided laborers; and different agencies on the committee provided technical planning, fertilizers, and plant materials. Tree planting and revegetation were supervised by the U. S. Forest Service. Mixed hardwoods were planted on sites subjectively judged "better." Virginia and pitch pine were planted on poorer sites, and black locust was planted on soils judged to be of the poorest, but plantable quality (W. G. Vogel, personal communication). Grasses and fertilization were limited to small areas of the mine which were avoided in this study.

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[2] The Kentucky Strip Mine Research Coordinating Committee was made up of the following organizations: Kentucky Coal Association; Kentucky Department of Natural Resources; Kentucky Reclamation Association; University of Kentucky; Northeastern Forest Experiment Station, U. S. Forest Service; and Tennessee Valley Authority.

Forest productivity of the mined site was studied in 1983 and the results were published by Wade et al. (1985).

Sampling

Three types of vegetation were chosen for this study: mixed hardwoods, pine, and black locust. Each vegetation type was repeated in plantations in the east, center, and west regions of the mine. Mixed hardwoods consisted of yellow-poplar, sycamore, red oak, white oak, sugar maple, red maple, and green ash in the center plantation, and yellow-poplar, sycamore, and red maple in the east and west plantations. Pine consisted of Virginia and pitch pine in the east and Virginia pine only elsewhere. Black locust was planted as a monoculture, but the stands are breaking up and red maple is now an important codominant.

In each plantation, four sample points were randomly chosen with the constraint that each point would be located on a nearly level surface so as to minimize microtopographic effects. At each sample point, a 500-cm^2 quadrat was placed on the surface of the O horizon and the inside litter was cut free of outside materials. The litter and all organic materials down to the mineral soil surface were collected, bagged, and returned to the laboratory. Thickness of the O horizon was measured at four points on the perimeter of the quadrat and the mean was recorded. A soil pit was dug to approximately 30 cm, and thickness of the developing A horizon was measured. Percent stone content of each horizon was estimated, parent material was noted, and soil structure described. Representative soils in each planting were photographed. Soil samples were taken from the entire thickness of the A horizon. B horizon soils were sampled from the top of the B horizon to 10 cm below the A B interface. Obvious presence of soil fungi, millipedes, and earthworms was noted when they occurred.

Laboratory

Upon return to the laboratory, O horizon samples were oven dried at 65°C and weighed to determine forest floor biomass, ground in a Wiley mill to pass a 0.5-mm screen, then pulverized in a tungsten carbide shatterbox. Mineral soil samples were air-dried, stone was removed, and the remaining soil ground and passed through a 2-mm sieve.

Total nitrogen (Kjeldahl) was determined on subsamples of the O, A, and B horizons (Tecator Inc. 1979). Subsamples of the O horizon were ashed at 500°C and dissolved in 10 percent HCl; and P, K, Ca, Mg, Mn, Fe, Cu, Zn, B, Na, Al, Si, Co, Ti, Ni, Cr, and Pb were determined by DC arc plasma emission spectroscopy. Mineral soils were leached with a double acid extract and P, K, Ca, Mg, Mn, Fe, Cu, Zn, B, Na, Al, Si, Co, Ti, Ni, Cr, and Pb in the extracts were determined by DC arc plasma emission spectroscopy. Organic matter was determined by loss on ignition (Page 1982), and soil pH was determined in 1:1 soil: water (Page 1982). Exchangeable acidity and exchangeable aluminum were determined by the KCl extract method, and conductivity was determined by conductivity meter (Page 1982).

Statistical Analysis

The intent of the statistical analysis was to investigate differences among the soil horizons as well as among vegetation type for the measured soil physical and chemical characteristics. Three types of means were calculated: (1) the mean of each variable for each horizon, (2) the mean of the difference between the A and B horizon for each variable, and (3) the mean of the ratio of the A horizon to the B horizon value for each variable. The A to B horizon ratios were used to investigate vegetation effects on soil development because the original choice of plantation types was not random; mixed hardwood stands had been established on the best planting sites. The ratios express degree of differentiation of soil horizons in spoils of differing quality. One way analysis of variance (ANOVA) was used to determine statistical differences among the means due to vegetation. Variation among locations is included in the error for these tests. Vegetation effects were tested for O horizon values, differences between A and B horizon values, and ratios of A to B horizon values. Paired t-tests were used to test overall differences between A and B horizon values ignoring vegetation type and location. The level of significance for all tests was set at $\alpha = 0.05$ unless otherwise indicated in tables. Data were analyzed using the MINITAB package (Ryan et al. 1982) and SAS (SAS Institute Inc. 1985).

RESULTS

Forest Floor

Distinctive differences in the forest floor O horizon due to forest vegetation type were immediately noticeable. The pine plantations had a thick carpet (overall mean of 3.5 cm) of nearly undecomposed pine needles (table 1). The mixed hardwoods O horizons were significantly ($\alpha = 0.05$) thinner (mean 2.4 cm). The mixed hardwoods and black locust appeared to have better decomposition at the litter: soil interface than did the pine plantations. Fungal mycelia were visible in the lower parts of the O horizon in 67 percent of the pine samples, 42 percent of the hardwoods, and 25 percent of the black locust.

Litter weights (g/m^2) also varied significantly ($\alpha = 0.05$) among vegetation types (table 1). Litter weight was greatest under pine and least under mixed hardwoods.

Soil Weathering

Stone content of A and B horizons was not significantly related to vegetation type, but significant differences were noted in different areas. Stone content of the B horizon did not differ significantly, but there were significant differences in the A horizon. A:B stone values suggest that surface stone in the eastern area has undergone significant decomposition into soil size particles (table 2).

Soil Structure

Soil structure in the A horizon was predominantly weak fine granular under pine and the mixed hardwoods. Black locust stands had mostly weak very fine granular structure in the A horizon.

B horizon structure was predominantly weak, fine, or medium angular blocky to massive under pine. Structure under black locust was more commonly weak, very fine granular to moderate fine granular. The hardwood stands were intermediate to the other stands in B horizon structure.

Horizon Differentiation

Differences in A horizon thickness were not significant among vegetation types ($\alpha = 0.05$) due to the larger amount of variation among sample locations. Site variables other than vegetation were obviously also influencing rate of A horizon formation.

Of the 23 soil chemical variables covered in this study, 15 showed significant differentiation of A and B horizons (table 3).

Soil organic matter analysis was confounded by coal fines and carbon in dark shales (table 3). Organic matter content was high as a result, but this is mostly relatively inert fossil carbon, not the more active humic materials formed from recent biotic activity. Nevertheless, there was an overall significantly greater amount of organic matter in the A horizon, which is consistent with the observed A horizon formation.

Soil reaction differences between horizons has not developed although pH has generally risen since plantation establishment (Wade et al. 1985). There were no

Table 1.--Soil horizon thickness and stone content by vegetation type. (Means are given over standard deviations in parentheses. Means followed by the same letter are not significantly different, ANOVA followed by Tukey's-w, $\alpha = 0.05$. Means not followed by letters indicate no differences due to vegetation effects, ANOVA, $\alpha = 0.05$).

	O horizon thickness (cm)	O horizon mass (g/m^2)	A horizon thickness (cm)	A stone content (%)	B stone content (%)
Mixed pine	3.50 a (0.73)	525 a (144)	1.71 (1.01)	24 (19)	36 (24)
Mixed hardwoods	2.48 b (0.94)	317 b (125)	2.24 (1.07)	20 (19)	24 (17)
Black locust	3.18 ab (0.87)	412 ab (180)	3.06 (2.42)	26 (23)	25 (16)

Table 2.--A:B stone ratios by vegetation type and location. (Upper values are means; lower values are standard deviations.)

Vegetation	Location East	 Center	 West	 All
Mixed hardwood	0.29	1.00	1.00	0.76
	0.48	0.00	0.00	0.43
Mixed pine	0.30	1.25	0.64	0.78
	0.15	0.29	0.31	0.48
Black locust	0.38	1.00	1.34	0.91
	0.43	0.00	0.47	0.53
All	0.33	1.08	1.03	0.82
	0.36	0.19	0.41	0.47

significant differences between horizons in pH, or exchangeable aluminum (table 3). However, the A horizons had significantly greater conductivity and lower exchangeable acidity than the B horizons. This indicates that salts had increased in the A horizons relative to the B horizon, and total acidity due to both H and Al had decreased in the A horizon.

The major plant nutrients nitrogen, phosphorus, potassium, and calcium showed significant accumulation in the A horizon (table 3). Of the minor plant nutrients, magnesium, manganese, zinc, and boron showed significant accumulation in the A horizon. Copper was more abundant in the B horizon. Sodium was significantly higher in the A horizon. Extractable aluminum, silicon, and iron did not show differences between soil horizons. The non-nutritive heavy metals lead, titanium, and chromium showed significant accumulation in the A horizon, but nickel and cobalt did not.

Vegetation Effects on Soil Development

The mixed pine, mixed hardwoods, and black locust stands had significant differences in element concentrations in the O horizon (table 4). Nitrogen concentrations were significantly higher under the black locust stand, probably due to nitrogen fixation. Phosphorus was significantly higher in mixed hardwoods litter than in the black locust litter. Calcium and magnesium concentrations were significantly higher in the mixed hardwood litter than in the other two stand types. Copper, zinc, and nickel were significantly more concentrated in mixed hardwoods and black locust litter than in the pine litter. Silicon was significantly higher in mixed hardwoods litter than in the pine litter.

Vegetation showed significant effects on mineral soil horizon differentiation (A:B horizon ratios) for 8 of the 23 soil chemistry variables (table 5). The mixed hardwoods showed the greatest differentiation in pH values between the A and B horizons. Exchangeable acidity (which includes acidity due to aluminum) tended to be lower in the A horizon soils than in the B horizon, and the differentiation was greatest under mixed hardwoods. The greatest differences in conductivity were under mixed hardwoods. Among the plant nutrients, nitrogen, zinc, and boron enrichment of the A horizon was significantly greater under mixed hardwoods. Sodium enrichment was greatest under hardwoods and least under pine. Of the heavy metals, only nickel showed differential effects of vegetation on A horizon enrichment; it was greatest under the mixed hardwoods.

Soil Fauna

Millipedes, and less commonly earthworms, were noted in half of the pine samples. None were noted in the other two vegetation types.

DISCUSSION

Residual soil development is normally a process that occurs over geologic time periods (Buol et al. 1973). At mined sites, mechanical disruption of consolidated subsurface layers and mixing of materials provides an atypical parent material with much more surface area exposed to weathering. Apart from this, it is expected that soil formation has for the most part followed generally accepted processes on this mine.

Soil development normally proceeds with accumulation of an organic layer over mineral soil and the development of a discernable A horizon. Plant nutrients generally accumulate in mine soils of low initial fertility (Vogel 1987). Other important chemical properties include modification of soil reaction and the liberation and leaching or concentration of potentially toxic materials such as aluminum.

At Fonde, three different criteria, visual evidence of soil horizon differentiation, O horizon chemistry, and mineral soil chemistry all suggested that rapid soil development is taking place.

Visual examination showed obvious differences in the soil profile. The profile had changed from an initially more or less homogeneous mass to a series of three horizontal layers. An O horizon was present on the surface and an A horizon had developed in the upper few centimeters of mineral soil.

The lower part of the profile showed some weathering of parent material although it still resembled the parent mine spoils. For the study, this was termed a B horizon (Wade et al. 1985). Whether or

Table 3.--Chemistry of developing soil horizons arranged in order of strength of differentiation based on T value from paired t-tests of A and B horizon values. A horizon mean value and standard deviation are given above those of the B horizon.

Variable	Unit	Mean	s.d.	T	α
Pb	ppm	2.51	0.92	9.45	.001
		1.53	0.73		
Conductivity	Mmho	0.151	0.041	8.90	.001
		0.088	0.032		
B	ppm	0.368	0.155	7.52	.001
		0.152	0.080		
Organic matter	%	9.82	3.22	6.79	.001
		7.21	3.42		
P	ppm	12.7	10.6	5.81	.001
		6.1	7.7		
K	meq/100g	0.255	0.082	5.30	.001
		0.188	0.040		
N	%	0.340	0.186	5.08	.001
		0.226	0.139		
Ti	ppm	1.54	0.43	4.85	.001
		1.18	0.36		
Mn	ppm	133	150	4.24	.001
		41	37		
Mg	meq/100g	1.94	1.74	4.14	.001
		1.20	1.02		
Cu	ppm	2.98	1.64	-3.67	.001
		4.06	1.44		
Exchangeable acidity	meq/100g	4.17	3.16	-3.58	.001
		5.05	3.31		
Cr	ppm	0.154	0.101	3.56	.01
		0.104	0.056		
Ca	meq/100g	2.64	3.52	3.40	.01
		0.71	0.71		
Na	meq/100g	0.044	0.015	3.30	.01
		0.034	0.010		
Zn	ppm	11.5	11.7	2.81	.01
		7.1	5.5		
Ni	ppm	4.72	8.46	1.61	ns
		2.70	1.85		
Co	ppm	1.96	1.40	1.92	ns
		1.60	0.94		
pH	pH	4.62	0.67	1.93	ns
		4.50	0.52		
Fe	ppm	138	87	0.77	ns
		131	77		
Al	ppm	462	337	0.53	ns
		444	369		
Exchangeable Al	meq/100g	4.70	10.4	0.41	ns
		4.07	3.0		
Si	ppm	19.5	15.3	-0.29	ns
		20.2	10.6		

Table 4.--Element concentrations in the O horizon under different vegetation types. (Mean values are given above standard deviations in parentheses. Means followed by the same letter are not significantly different; Tukey's-$\underline{w}$ following ANOVA, α = .05).

	N	P	K	Ca	Mg	Mn
	%	ppm				
M. pine	1.59 b (0.55)	944 ab (182)	831 (305)	2432 c (1327)	678 b (1113)	2333 (856)
M. hardwood	1.53 b (0.28)	1069 a (214)	1108 (299)	5093 a (1173)	2576 a (1327)	1944 (963)
B. locust	2.20 a (0.52	875 b (155)	881 (881)	3853 b (1634)	854 b (812)	1793 (996)

	Fe	Cu	Zn	B	Si	Na
	ppm					
M. pine	7123 (5242)	9.9 b (2.7)	66.0 b (24.7)	31.6 (9.1)	3972 b (1013)	95 (35)
M. hardwood	9294 (6865)	16.2 a (4.8)	128.9 a (90.5)	37.1 (5.3)	5151 a (716)	114 (22)
B. locust	5616 (3254)	15.8 a (4.2)	176.9 a (59.4)	36.4 (5.6)	4544 ab (1081)	105 (32)

	Al	Co	Ni	Ti	Cr	Pb
	ppm					
M. pine	4721 (2274)	8.3 (3.3)	21.9 b (6.8)	62.8 (17.2)	9.2 (3.1)	41.4 (17.4)
M. hardwood	4166 (3467)	15.2 (10.9)	39.1 a (17.6)	78.1 (19.9)	11.1 (3.0)	37.9 (3.2)
B. locust	4571 (2805)	12.2 (5.0)	34.8 a (11.8)	69.9 (20.4)	9.1 (2.8)	41.1 (10.6)

not significant weathering of primary minerals in the B horizon has occurred, there has been some structure formation and an obvious "uncementing" of particles of sedimentary rocks. (The mining process that shattered this parent material could be called the primary "weathering" process.) Time required for rock weathering is not necessarily long. Hilger (1897 cited in Jenny 1941) exposed rock particles 10-20 mm in diameter to the atmosphere for 17 years. Stuben sandstone became 90 percent soil size particles (< 0.5 mm) in that time. Jenny (1941) gives several other examples of rapid physical weathering as well as examples of rocks with high stability. Differences in A:B stone ratios in the different areas of the mine indicate that local site differences such as parent materials and microclimate might be affecting rock weathering. Geyer and Rogers (1972) and Schafer et al. (1980) noted rapid weathering of spoil rock into soil-sized particles.

Differentiation of A and B horizons occurred in less than 22 years. Expected differences in the rate of A horizon development under different vegetation types could not be proved due to the high amount of variation within plantations and between different areas under the same vegetation type. We suspect that microclimate, parent material differences, and erosional removal rates at least are confounding factors. The mean A horizon thickness for all sample points was 2.3 cm. Davidson (1981) studied soil development on 45- to 60-year-old surface mines in Pennsylvania. He found A and B horizon mean thicknesses of 5.3 cm and 21.2 cm developed under pine and spruce plantations that were being invaded by hardwoods. Thomas and Jansen (1985) found 10 cm A horizons in 50- to 64-year-old mine spoils. A spoil composed of loess in Iowa developed a 31 cm A

Table 5.--Vegetation effects on soil horizon differentiation expressed as means and standard deviations (in parentheses) of A horizon:B horizon ratios. (Means followed by the same letters are not significantly different: ANOVA followed by Tukey's-w, $\alpha = 0.05$. Means not followed by letters did not show significant differences due to vegetation: ANOVA, $\alpha = 0.05$).

	pH	Cond.	Exch. Acid	Exch. Al	O.M.	N	P	K
M. pine	1.02 b (0.04)	1.47 b (0.31)	0.84 a (0.17)	1.24 (1.47)	1.44 (0.78)	1.30 b (0.58)	2.38 (0.96)	1.29 (0.36)
M. hardwood	1.09 a (0.09)	2.42 a (0.83)	0.50 b (0.47)	0.38 (0.44)	1.94 (0.78)	2.50 a (1.15)	3.00 (2.25)	1.59 (0.44)
B. locust	0.97 c (0.04)	1.68 b (0.58)	1.00 (0.22) a	0.93 (0.24)	1.37 (0.46)	1.57 b (0.48)	2.87 (2.23)	1.29 (0.51)

	Ca	Mg	Mn	Fe	Cu	Zn	B	Si
M. pine	3.79 (2.27)	1.66 (0.57)	5.80 (2.73)	1.40 (0.76)	0.76 (0.26)	1.31 b (0.63)	1.72 b (0.70)	0.89 (0.35)
M. hardwood	4.84 (4.09)	2.54 (1.61)	3.89 (2.81)	0.84 (0.57)	0.79 (0.53)	3.17 a (2.57)	4.18 a (1.87)	0.83 (0.17)
B. locust	6.28 (10.81)	1.54 (0.64)	3.18 (2.32)	1.30 (1.01)	0.76 (0.28)	1.36 b (0.66)	1.87 b (0.66)	1.82 (3.09)

	Na	Al	Co	Ni	Ti	Cr	Pb
M. pine	1.10 b (0.46)	0.96 (0.32)	0.94 (0.27)	1.29 b (0.71)	1.21 (0.35)	1.44 (0.50)	1.74 (0.55)
M. hardwood	1.76 a (0.51)	1.23 (0.61)	1.75 (1.08)	2.71 a (1.82)	1.56 (0.41)	1.78 (0.84)	1.98 (0.62)
B. locust	1.32 ab (0.73)	1.24 (0.42)	1.19 (0.84)	1.17 b (0.63)	1.31 (0.45)	1.60 (1.15)	1.68 (0.69)

horizon in 100 years (Hallberg et al. 1978).

A horizon thickness was determined visually from color differences in the sides of the soil pits. The A horizon organic matter content was significantly greater than that of the B horizon. Coal fines and carbon in dark shales caused great variability in the data so that more subtle vegetation effects could not be determined.

Soil reaction and salts content has decreased since vegetation establishment (Wade et al. 1985). There was no overall significant differentiation in soil reaction between mineral soil horizons, but testing for vegetation effects showed significant differences. A and B horizon ratios of pH, conductivity, and exchangeable acidity (which includes acidity due to aluminum) were greatest under mixed hardwoods; differentiation under other vegetation types was significantly less. Lack of overall differentiation may be due to opposite trends under hardwoods vs. pine.

Accumulation of major plant nutrients in the A horizon is probably due in part to a "pumping action" (Black 1968, Klopatek 1978) by vegetation. This differentiation of nutrients can be detected after only a short period, at least for K (Wade 1985). Another possible mechanism of surface concentration is by soil solution movement to and evaporation from the soil surface. This is probably the case for salt accumulation. A third mechanism is accelerated leaching of ions from the B horizon (Birkeland 1974). Because some differences can be related to vegetation type in this and other studies (Wade 1985), it is suspected that all three mechanisms are operable here. Hallberg et al. (1978) and Thomas and Jansen (1985) also found A horizon accumulation of P in spoils.

Potassium enrichment of developing A horizons in spoils has also been documented by Shafer et al. (1980) and Thomas and Jansen (1985).

Minor plant nutrients have followed the pattern of the major nutrients except for copper. It may be that copper levels in the soils were initially well above the requirements or usability of vegetation and that downward leaching has exceeded surface deposition by vegetation.

The extent of differentiation between soil horizons differs considerably between elements. Based upon magnitude of mean horizon differences and the consistency of that differentiation (ranked by T values from paired t-tests, table 3), lead, conductivity, boron, organic matter, phosphorus, potassium, and nitrogen best differentiated the mineral soil horizons. Elements such as iron, silicon, and aluminum, which tend to form insoluble hydroxides in soil environments were least differentiated between horizons.

Jenny (1941) cites many examples and mechanisms of vegetation effects on soil development. He shows how different vegetation types can have significant effects in a few decades. The results of this study follow what Jenny's examples predict, particularly in visible attributes of O and A horizon development. Vegetation has three possible mechanisms for causing differential soil horizon development: (1) Plant species differentially remove elements from the soils. These element use ratios are preserved in litterfall and can affect soil surface chemistry through litter leaching and decomposition. (2) Plant species with nitrogen-fixing symbionts increase nitrogen availability in the soils and alter the availability or mobility of other elements that are tied up in organic matter. This additional nitrogen also alters magnitudes of many biological processes. (3) Some plant species produce litter rich in organic acids or chelating agents that alter the weathering and leaching patterns of the surface soils.

The suspected better original fertility or more favorable soil reaction and parent material of the mixed hardwoods plantations *may* have been responsible for the greater degree of horizon differentiation seen there. However, the higher nitrogen fertility of the black locust did not lead to greater differentiation between horizons. So, initial fertility differences *per se* can't be used to explain away significantly greater differentiation of nitrogen, zinc, boron, sodium, and nickel under mixed hardwoods. Vegetation effects may well have been a major operative factor. More research is needed to settle the question of the relative influences of initial fertility vs. vegetation on soil development.

The thickest and heaviest O horizons developed under pine; the thinnest and lightest developed under mixed hardwoods. These O horizons may well differ in organic acid release, insulating properties, and absorption of water before it reaches the soil surface during precipitation events. It is expected that differences in concentrations of O horizon elements will emphasize differences in A horizon element concentrations and development as the decay of O horizon organic matter progresses. Nutritive and nonnutritive elements were generally more concentrated in the O horizon by a factor of 10 over the available amounts in the A horizon. Vegetation type showed significant influences on N, P, Ca, Mg, Cu, Zn, Si, and Ni concentrations in litter. The O horizon differences in nutrient capital sequestration will be examined in the near future.

There are now numerous reclaimed surface mines with diverse parent materials, topographic positions, surface treatments, and established vegetation types two or more decades in age. These should now be studied to determine the effects of different reclamation practices on soil development and site productivity.

SUMMARY AND CONCLUSIONS

This study of soil development under forest plantations on a surface mine showed that O and A horizons had developed over B horizons in 22 years or less. In that time, a large proportion of surface stone had weathered to soil-sized particles on some areas of the mine.

The O horizon was significantly thickest and heaviest under pine. The mean A horizon thickness was quite variable around a mean of 2.3 cm and was unaffected by vegetation type after 22 years. A horizon organic matter content was 2.6 percent greater than that of the B horizon. Soil structure has developed in the A horizon and also was visible in some of the B horizon samples.

Soil pH generally increased since plantation establishment. There were no overall pH differences between A and B horizons, but there were significant A:B pH differences among vegetation types. Soil conductivity was greater in the A horizon, and effects attributable to vegetation were evident.

Major and minor plant nutrients (except for Cu) are more concentrated in the A horizon than in the B horizon. Heavy metals Pb, Ti, and Cr were significantly more concentrated in the A horizon; Ni and Co were not. Iron, Si, and Al showed no horizon differentiation.

Vegetation type appeared to have significant effects on horizon A:B ratios in available N, Zn, B, Na, Ni, and pH, exchangeable acidity, and conductivity. O horizons had significant differences in concentrations of N, P, Ca, Mg, Cu, Zn, Si, and Ni attributable to vegetation type.

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MINESOIL FACTORS INFLUENCING THE PRODUCTIVITY OF NEW FORESTS ON RECLAIMED SURFACE MINES IN SOUTHWESTERN VIRGINIA[1]

J.L. Torbert, J.A. Burger, and W.L. Daniels[2]

Abstract.-- Coal companies and regulatory agencies have not been totally cognizant of the establishment requirements and long-term nature of forest trees that will ultimately cover 70-90% of the reclaimed land in Virginia and parts of adjoining states. Reclamation and revegetation guidelines primarily emphasize site conditions and establishment techniques for herbaceous ground cover rather than conditions and requirements for woody plant species. Several research projects in southwestern Virginia show that reclamation for trees requires minesoil construction techniques that often differ from those used for the establishment of hayland/pasture. Overburden type and minesoil depth dramatically affect tree growth and wood production. An overburden placement study was established to investigate the effects of various mixtures of sandstone and siltstone overburden on the growth of pitch x loblolly pine (Pinus xrigitaeda) seedlings. After 4 years, trees in sandstone minesoils had more than five times the stem volume than trees in siltstone minesoils (685 cm^3 vs 123 cm^3). A highly significant linear relationship (R^2=.91) existed between stem volume and percent sandstone in the overburden mixture. In this study sandstone-derived minesoils were better for tree growth because they have a lower pH, lower levels of soluble salts, and fewer coarse fragments than siltstone-derived minesoils. A study to determine which minesoil properties influenced the growth of 8-year-old white pines (Pinus strobus L.), ranging in height from 0.9 m to 6.9 m, revealed that minesoil depth to a restrictive layer and soluble salt levels were the two most important factor affecting tree performance.

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INTRODUCTION

Most reclaimed surface mines in the Appalachians will ultimately return to forest land, either as the result of planned reforestation efforts, or through natural succession on "hayland" and "pasture land" abandoned after bond release. During the first four to five years following the inception of PL 95-87, "hayland/pastureland" was the dominant post-mining land use permitted. The extra expense of planting trees discouraged most operators from designating managed or unmanaged forest land as post-mining land uses. More recently, however, a combination of incentives and disincentives caused operators to switch to unmanaged forest land either because 1) state regulations required pasturing or hay harvests prior to bond release; 2) repairs needed to maintain the ground cover were more costly in the long run than tree planting; or 3) landowners were interested in the productive potential of forest crops. The primary concern of most coal companies is obtaining immediate ground cover and achieving adequate tree survival for bond release. The long-term productivity of these new forests is, at most, a secondary concern of operators, but it should be a primary concern of landowners.

The establishment of "unmanaged forest land" generally requires the same reclamation and revegetation techniques used to establish hayland/ pasture, with the additional step of planting about 1,000 to 1,500 trees/ha. The predominant crop tree species for reclamation in Virginia is white pine (Pinus strobus L.), which is usually planted along with various nitrogen-fixing tree and shrub species such as black locust (Robinia psuedoacacia L.), autumn olive (Elaeagnus umbellata L.), and bicolor lespedeza (Lespedeza bicolor Turcz).

To date, most research conducted in the eastern U.S. has shown that prime farmland can be returned to crop production and that most minesoils can be used for pasture. Until recently, however, little work has been done to demonstrate the productive potential of forest crops on minesoils. Given the large acreage now being planted to trees, technical information was needed for reclamation guidelines that would ensure productive sites for forest crops. To meet this need, a comprehensive research program was begun in 1980 by the Forestry Department at Virginia Polytechnic Institute and State University with initial funding by the Powell River Project.[3/] The purpose of this paper is to summarize results from several studies that identified minesoil factors that directly influence forest productivity.

EFFECT OF OVERBURDEN SELECTION ON TREE GROWTH

Coal seams in the Virginia Appalachians and surrounding states are generally overlain by overburden strata of sandstone and siltstone. These layers of rock are blasted and removed during the mining process and must be replaced during reclamation. Native soils are often shallow and steep making it difficult for coal operators to stockpile and replace these soils during reclamation. Consequently, "topsoil substitute" variances are frequently issued when coal operators can demonstrate that overburden materials would be as productive as native topsoil.

Sandstone and siltstone differ in their physical and chemical characteristics. These differences can affect revegetation success. In a preliminary greenhouse study at Virginia Tech, Preve et al. (1984) found that a sandstone mine spoil was a better growth medium than a siltstone spoil for pine (Pinus spp.) seedlings. The sandstone overburden had fewer coarse fragments, better aeration porosity, and lower levels of soluble salts. The effects of overburden type on tree growth was further studied in the field. A rock mix study was established to compare the effects of various sandstone/siltstone overburden mixtures on the growth of pitch x loblolly pine hybrid (Pinus xrigitaeda) seedlings.

Study Methods

The study plots were constructed during the winter of 1982 on a previously mined flat bench in Wise County, Va. The study consisted of four replications of five overburden mixes: pure sandstone (SS), pure siltstone (SiS), 2:1 SS:SiS, 1:1 SS:SiS, and 1:2 SS:SiS. Overburden from an adjacent mining operation involving the Taggart and Taggart Marker coal seams of the Marcum Hollow member of the Upper Wise Formation was used. The strata were chosen for this study because of their known low sulfur content and relatively high carbonate content. Sandstone and siltstone overburden were stockpiled separately. The spoils were mixed in the required ratios and placed in the center of 3- by 6-m plots. After all spoil mixtures were in place, each pile was graded flat with a small (D-4) bulldozer, taking care to minimize compaction. After grading, the area was level with a spoil depth of 1.2 m over a highly compacted underlying bench.

The entire study area was fertilized with 1,120 kg/ha of 15-30-15 granular fertilizer, consisting of ammonium nitrate, diammonium phosphate, and potassium chloride. During May 1982, all plots were mulched with straw (2300 kg/ha) and hydroseeded with a slurry containing Kentucky-31 tall fescue (Festuca arundinacea Schreb., selection Ky-31) and wood fiber mulch (840 kg/ha).

[3/] The Powell River Project, initiated by the Penn Virginia Resources Corporation, is a consortium of industry, several universities and colleges in Virginia, and various State and Federal agencies, and supports research devoted to enhancing the productive land-use of surface mined land and the general welfare of citizens in the coal-mining counties of Virginia and surrounding states.

The pine seedlings were grown in Spencer-Lamaire root trainers (Hillson model, 150 cc/cavity) for 16 wk prior to planting in the study plots. In April 1983 half of each plot was broadcast sprayed with a 2% glyphosate solution to kill the ground cover, and containerized pine seedlings were planted on a 0.75- by 0.75-m spacing within the sprayed area. Seedlings were planted with a 21 g slow-release fertilizer pellet (20-10-15).

After three growing seasons, a composite soil sample was collected from each plot. Soil samples were taken by collecting all soil within two 30- by 30-cm areas, randomly located within each plot, to a depth of 20 cm, and compositing these samples for analysis. Tree growth was measured after the fourth season.

Results

Overburden samples were analyzed for coarse fragment content, particle size distribution of the soil fraction (particle size < 2mm), and percent moisture retention at 3, 5, and 15 bars using a pressure membrane extractor (table 1). Coarse fragment content was high in all rock mixes, but was highest in the siltstone plots (74%). Coarse fragment content in siltstone plots was significantly greater than the sandstone plots (52%). Within the soil fraction, there were significant differences in the amount of sand and silt between treatments, but no relationship between rock-mix and clay content was observed. Despite these differences in sand and silt content, the textural class of all soils was a sandy loam. Moisture retention was highest in the siltstone plots and decreased proportionally as sandstone was added. When the value for the 5 bar water content was multiplied by percent soil to estimate the total amount of water available for trees, total moisture was significantly greater in the sandstone plots (30 g/kg vs 20 g/kg), because these plots had almost twice as much soil (48% vs 26%).

Table 1. Minesoil physical properties as affected by rock type.

Rock Mix	Coarse Fragment Content	Particle Size			Moisture Retention		
		sand	silt	clay	3 bars	5 bars	15 bars
	- - - - -	- % - - -	- - - - -	- - -	- - - -	g / kg	- - -
Sandstone	52 b[1]	74 a	15 d	11	69	62 b	31
2:1 mix	57 ab	71 ab	18 c	11	70	64 b	39
1:1 mix	64 ab	68 bc	20 b	12	71	68 ab	37
1:2 mix	63 a	64 c	23 ab	13	80	71 ab	35
Siltstone	74 a	57 d	29 a	14	86	78 a	40

[1] Values within a column followed by the same letter are not significantly different according to Duncan's Multiple Range Test at the 0.05 level of significance

Chemical analyses included pH, electrical conductivity (EC) of a 1:5 soil:water extract, total Kjeldahl nitrogen (N), and ammonium acetate-extractable phosphorus (P), potassium (K), calcium (CA), and magnesium (Mg) (table 2). Overburden mix was significantly related to pH, EC, N, K, Ca, and Mg, but not P. Soluble salts (as indicated by EC), pH, and nutrients were highest in the siltstone plots and lowest in the sandstone plots. The pH ranged from 7.9 (siltstone) to 6.9 (sandstone), which is high compared to many minesoils, and higher than levels considered ideal for pines (pH 5.0-5.5). Cementing carbonates weather to produce high pH and salt levels during the first few years after placement. Electrical conductivity followed the same trend as pH, and both variables were highly correlated with each other (P =.0001; r=-.87).

Table 2. Minesoil chemical properties as affected by rock type.

Rock Mix	pH	EC	Total N	NH_4OAC-Exchangeable Nutrients			
				P	K	Ca	Mg
		dS/m	g/kg	- - - - - -	- ug/kg	- - -	- - -
Sandstone	6.9 c[1]	0.4 d	0.7 c	47 a	49 c	435 d	162 b
2:1 mix	7.1 bc	0.7 c	0.9 bc	56 a	62 b	548 c	206 a
1:1 mix	7.3 bc	0.7 c	0.9 bc	53 a	60 b	562 c	215 a
1:2 mix	7.5 ab	0.9 b	1.0 ab	51 a	63 b	666 b	220 a
Siltstone	7.9 a	1.3 a	1.6 a	42 a	73 a	777 a	227 a

[1] Values within a column followed by the same letter are not significantly different according to Duncan's Multiple Range Test at the 0.05 level of significance

Tree growth was greatly affected by rock mix (table 3). Tree height, diameter, and volume increased as the amount of sandstone increased in the rock mix. A linear relationship between tree volume and percent sandstone in the rock mix was highly significant (P = .0108; R2 = .91). Trees in pure sandstone plots had over five times more stem volume than trees in siltstone plots.

Since this study involved only two specific overburden strata from a localized region, these results cannot be extrapolated to all sandstone and siltstone overburdens. The study does, however, demonstrate the over-riding influence that overburden characteristics can have on tree growth, and it provides justification for suggesting that the best overburden material be placed at the surface.

Table 3. Effect of rock mix on hybrid pine growth after 4 years.

Rock Mix	Tree Growth		
	Height	Diameter	Volume[1]
	- cm -	- mm -	- cm^3 -
Sandstone	146.2 a[2]	40.4 a	685 a
2:1 mix	141.4 ab	37.8 ab	621 ab
1:1 mix	111.4 bc	30.8 b	338 bc
1:2 mix	111.5 bc	30.6 b	337 bc
Siltstone	84.8 c	21.8 c	123 c

[1] Volume = 1/3 x 3.14 x $(\text{diameter}/2)^2$ x Height.

[2] Values within a column followed by the same letter are not significantly different according to Duncan's Multiple Range Test at the 0.05 level.

EFFECT OF MINESOIL DEPTH ON TREE GROWTH

Another study was conducted to determine which minesoil factors were influencing the growth of white pines that had been growing for 8 yrs on a series of reclaimed benches in southwestern Virginia. Thirty-four white pines were systematically selected to cover a range of tree sizes and obvious minesoil/site properties (surface soil color, parent material, presence or absence of ground cover, etc.). Individual trees were selected for this study if their size was representative of all immediately surrounding trees. This selection process increased the likelihood that growth performance reflected site conditions.

Study Methods

A 1-meter-deep backhoe pit was dug at the base of each tree, and a taxonomic soil description was obtained from each pit with special emphasis given to identifying restrictive layers of rock or traffic pans that would impede root growth. Clods collected from these layers had bulk densities of at least 1.7 g/cm^3. Other minesoil physical properties analyzed were surface soil (0-10 cm) bulk density, coarse fragment content, and particle size distribution of the soil fraction. Routine chemical analyses performed on the surface soil included pH, EC of a 1:5 soil/water extract, sodium bicarbonate-extractable P, ammonium acetate-extractable K, Ca, and Mg, total Kjeldahl N, and anaerobic mineralizable N.

Results

Correlations between minesoil variables and total tree height are presented in table 4. Depth to a restrictive layer, EC, and extractable K and Mg were correlated with growth ($P<0.1$). Rooting volume index (rooting depth x percent soil fraction) was the most highly significant variable in this study, accounting for almost 50% of the variation in tree height. Minesoil nutrient levels were not correlated with growth, indicating that, on these sites, minesoil fertility was not as influential as minesoil physical properties on tree growth. This was further substantiated by foliar analyses which showed no relationship between pine needle tissue concentrations and tree performance.

Tree height ranged from 0.9 m to 6.9 m and averaged 2.5 m. To estimate the effect that these differences might have had at the time of tree harvest, white pine site index (SI_{50}) was estimated at the location of each tree (from total height) with Beck's (1971) equation for site index. Site index ranged from approximately 10 m to 36 m with an average of 25 m.

Site index was plotted as a function of the square root of rooting depth (fig. 1). Although there is a considerable scatter of points along the regression line, it is evident that rooting depth can have a strong effect on site quality. According to Doolittle (1958), the average site quality for white pine in the Southern Appalachians is approximately 24 m. The regression equation developed from this study indicated that a site index of 24 corresponded to a rooting depth of approximately 75 cm. No tree with a site index of 24 m or greater was found on minesoil depths of less than 30 cm. These data suggest that better-than-average growth for the Southern Appalachians can be achieved if at least 75 cm of nontoxic minesoil is left at the surface in an uncompacted state.

Table 4. Correlations of selected minesoil properties with the height of thirty-four 8-year-old white pines growing on reclaimed benches in Wise Co., Va.

Minesoil Property	Significance	R-value
Depth to a restrictive layer (cm)	.0003	.58
Soil-sized fraction (%)	ns[1]	—
Rooting Volume Index[2]	.0001	.71
Sand (%)	ns	—
Clay (%)	ns	—
Bulk density (g/cm^3)	ns	—
pH	ns	—
Electrical conductivity (dS/m)	.0090	-.43
Organic matter (%)	ns	—
Total soil N (%)	ns	—
Anaerobic mineralizable N (ppm)	ns	—
Extractable P[3] (ppm)	ns	—
Extractable K[4] (ppm)	.1050	-.29
Extractable Ca (ppm)	ns	—
Extractable Mg (ppm)	.0560	-.33

[1] indicates that minesoil variables are not significantly correlated with tree height at a significance level of 0.1 or greater.

[2] Rooting Volume Index = Depth x soil-sized fraction.

[3] Sodium bicarbonate extractable P.

[4] Ammonium acetate extractable cations.

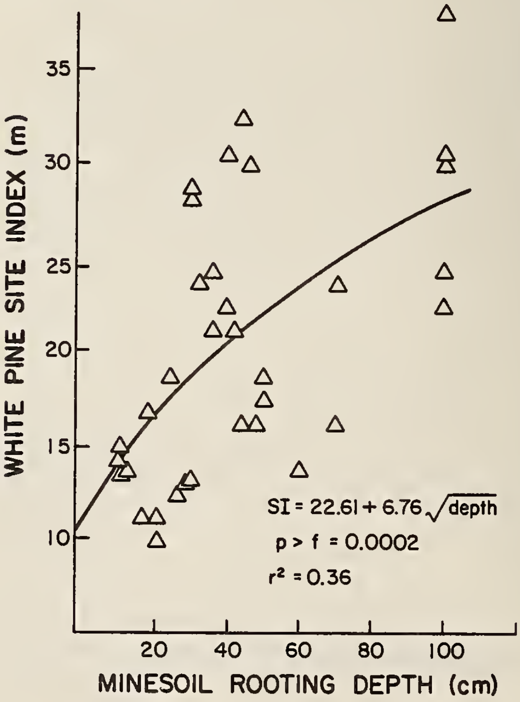

Figure 1. Relationship between projected site index and minesoil depth to a restrictive layer, for thirty-four 8-year-old white pines on reclaimed benches in Southwest Va.

SUMMARY AND CONCLUSIONS

These studies demonstrate the importance of minesoil physical properties on tree growth, and the impact that overburden selection and placement can have on these properties. This research agrees with the findings of Ashby et al. (1984) who reported excellent growth of black walnut, yellow-poplar, and white oak on 30-year-old minesoils. They stated that excellent tree growth can occur when trees are planted in deep, nontoxic minesoil, and are maintained free of competing vegetation. The largest trees in these Virginia studies were white pines growing in minesoils derived from brown sandstone. Brown sandstones originate from near the surface and are more oxidized compared to the deeper, gray sandstones. Brown sandstone usually has a lower pH, lower levels of soluble salts, and produces fewer coarse fragments than minesoils derived from gray sandstone or siltstone. Minesoils derived from this material are often deep and well-drained with a pH of 4.5 to 5.5 which is ideal for pines. Although the high level of oxidized iron can fix large quantities of P applied as fertilizer, trees are capable of utilizing fixed P due to the presence of mycorrhizal fungi that symbiotically colonize tree roots after a year or two (Schoenholtz et al., 1987). Results from these studies, as well as subjective evaluations of numerous pine plantings throughout the coal mining region of Virginia and surrounding states, suggest that non-pyritic, brown sandstone is the best topsoil substitute for tree establishment and growth.

Brown sandstone is often placed beneath the surface because the pH and P availability are too low to support the lush growth of grasses and legumes which are traditionally used for reclamation. Consequently, the potential long-term productivity of many sites that will ultimately become forest land is being sacrificed for the short-term perceived need of a lush dense herbaceous ground cover. These studies illustrate the need for landowners, coal companies, and regulatory agencies to evaluate overburden materials and placement techniques in light of the differnt site and soil requirements of the intended post-mining vegetation.

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REFORESTATION OF A ZINC SMELTER SUPERFUND SITE[1]

William E. Sopper[2]

Abstract.--Over 800 ha of forest vegetation have been destroyed on Blue Mountain at Palmerton, PA, primarily by emissions of Zn, Cd, Cu, Pb, and SO_2 from a zinc smelter operating since 1898. In 1982, the site was designated as a "Superfund" site. In 1985, a cooperative research effort was initiated to develop a remedial action program to mitigate the environmental damage. Field plot studies were conducted to determine the feasibility of using mixtures of dewatered municipal sludge and fly ash as amendments to facilitate the establishment of vegetation on the highly contaminated soil. Three mixtures of sludge (S) and fly ash (FA) were evaluated (1S:1FA, 2S:1FA, and 3S:1FA). The amendments were applied to 0.4-ha plots in May 1985. Seedlings of 10 tree species and hybrid poplar cuttings were planted on the plots in 1986 and 1987. Seedling survival was poor in 1986 due to the late planting date, but survival in 1987 was excellent. Species survival ranged from 44 to 91 percent across all treatments. The highest survival rate (80%) for all species was found on the 2S:1FA treatment. Larch and black cherry had the best height growth. Foliar concentrations of Cu, Ni, Cr, Co, and B were generally below the tolerance level for growth suppression in all species on all treatments. Foliar concentrations of Mn, Fe, Al, Zn, Pb, and Cd were all above the tolerance level in most species on all three treatments. However, no phytotoxicity symptoms were observed. Results to date indicate that all three sludge-fly ash mixtures were successful in facilitating tree seedling establishment on the highly contaminated soil.

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[1] Paper presented at the 1988 Mine Drainage and Surface Mine Reclamation Conference sponsored by the American Society for Surface Mining and Reclamation and the U.S. Department of the Interior (Bureau of Mines and Office of Surface Mining Reclamation and Enforcement), April 17-22, 1988, Pittsburgh, PA. The research described in this article has been funded wholly by the U.S. Environmental Protection Agency, Region III; it has not been subjected to Agency review and therefore does not necessarily reflect the view of the Agency, and no official endorsement should be inferred.

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INTRODUCTION

In 1900 the north slope of Blue Mountain at the Lehigh Water Gap in the vicinity of Palmerton, PA was a densely forested area of chestnut, white pine, and mixed oak species. Today, it is a barren, devastated, biological desert. Approximately fifty percent of the slope area is strewn with rocks and boulders exposed by severe erosion over the past 50 years which has removed about 30 cm of the original surface soil.

The major cause of denudation was emissions of Zn, Cd, Cu, Pb, and SO_2 from a zinc smelting plant which has been operating in Palmerton since 1898 (Buchauer 1973). In addition, the area was also subjected to extensive logging and frequent fires (Jordan 1975). Natural revegetation has been hampered primarily by the high Zn concentrations in the surface mineral soil and organic detritus material present on the area. Soil nutrients have been washed away, microorganism populations are virtually nonexistent, and the surface soils are droughty with extreme variations in microclimate. As a result the normal balance of vegetation, soil microorganisms, and the recycling of soil nutrients have been severely disrupted by the 50 years of accelerating denudation and erosion.

During the period 1977 to 1983 numerous attempts were made by the Soil Conservation Service to establish vegetation, both herbaceous and trees, on the contaminated soil on Blue Mountain. These attempts used various applications of lime and fertilizer, and species hoped to be tolerant were seeded or planted. Most of these experiments were failures and illustrated dramatically that the Blue Mountain site was too toxic to be revegetated by any conventional techniques.

The Blue Mountain site represents a unique set of reclamation challenges. First of all, the area is totally inaccessible to vehicles because the slopes are covered by rocks, boulders, and undecomposed tree stems. Access would only be possible by bulldozing new roads. The slopes are steep, averaging 30% and ranging from 25 to 100 percent. Most vehicles used to spread lime, fertilizer, or sludge must be able to traverse the site. This is not possible on this site, so that it would be necessary to use a spreading vehicle which could apply the amendments aerially considerable distances (30 to 45m) onto the slopes. Incorporation of the amendments, a usual practice, would also not be possible on this site. And lastly, the surface soil is highly contaminated with trace metals, providing another impediment to vegetation establishment. Background surface soil samples taken downwind of the smelter approximately at midslope on Blue Mountain contained 31,316 ppm of Zn, 5,225 ppm of Pb, and 1,248 ppm of Cd (Shoener et al. 1987). The normal ranges for uncontaminated soils in the United States are 10-300 mg/kg for Zn, 2-200 mg/kg for Pb, and 0.01 to 7.00 mg/kg for Cd (Allaway 1968). A considerable portion of the area is also covered with a layer of black humus detritus that appears to be undecomposed tree bark. Analyses of this material showed equally high concentrations of trace metals --29,475 ppm of Zn, 1,221 ppm of Cd, and 6,237 ppm of Pb. Soil samples taken to a depth of 90 cm indicated that the depth of adverse contamination for Zn (>200 ppm) and Cd (>5 ppm) ranged from 5 to 30 cm. As far as it could be ascertained, reclamation of such a site has never been attempted.

In 1982, the area was placed on the National Priorities List and designated as a "Superfund" site by the U.S. Environmental Protection Agency. Under a consent agreement signed September 25, 1985, a Remedial Investigation/Feasibility Study was initiated to find a remedial action program which would mitigate the environmental damage. Cooperating with the U.S. Environmental Protection Agency were the Department of Public Works, City of Allentown; Pennsylvania Power and Light Company; the Soil Conservation Service, USDA; and the Environmental Resources Research Institute, The Pennsylvania State University (Shoener et al. 1987).

It was quite obvious that attempting to plant or direct seed vegetation on the existing soil surface would be futile since natural revegetation had not occurred over the past 50 years. It is not possible for grass, legume, and tree species to germinate and survive when seeded directly on the highly contaminated soil. Thus, it was concluded that some type of growing medium had to be placed on top of the contaminated soil. Some possibilities were topsoil, peat-vermiculite potting mixtures, and waste products. Economics eliminated the first two possibilities, so attention was focused on local waste products. It was decided to investigate sludge and fly ash because of the potentially large volumes that might be needed. The hypothesis being evaluated is to determine if vegetation germination, survival, and growth can be facilitated by using various mixtures of sludge and fly ash as a growing medium on top of the contaminated soil to provide a nutrient support system for the vegetation until some part of the root system penetrated the highly contaminated surface soil (5 to 30 cm) to reach the uncontaminated subsoil. The assumption is that vegetation survival will be greatly enhanced once the roots reached the normal uncontaminated subsoil.

Since the sludge could not be incorporated, it did not seem feasible to apply sludge alone. Its poor physical characteristics (wetting and drying) when applied on the soil surface without incorporation would not be conducive to seed germination. Thus, the decision was made to use the fly ash in a mixture with sludge to make a more friable product.

Based upon analyses of dewatered digested sludge from the Allentown wastewater treatment plant and fly ash from the Pennsylvania Power and Light generating plant, the decision was made to evaluate three sludge-fly ash mixtures. The mixture ratios (on volume basis) selected for evaluation were 1S:1FA, 2S:1FA, and 3S:1FA.

GREENHOUSE EXPERIMENT

A greenhouse experiment was conducted over the 1985-86 winter period to test the hypothesis. Evaluations were made of the three sludge-fly ash mixtures, and 12 tree species were screened. The 12 tree species were seeded in containers 10 by 10 cm in area and 20 cm in height. Each container was filled with 5 cm of sand in the bottom, followed by 4 cm of contaminated soil from Blue Mountain, and then 10 cm of the various sludge-fly ash mixtures.

The seedlings were grown for 90 days. Measurements were made of height growth, foliar biomass, and root biomass. The latter were also analyzed for nutrients and trace metals. During harvesting, observations were made of root distribution and depth of root penetration. Root systems of most of the tree species developed sufficiently to penetrate through the sludge-fly ash mixture and the contaminated soil into the underlying sand layer. There was no evidence of any roots attempting to avoid entry into the contaminated soil layer. Foliar trace metal concentrations were generally low for all tree species and no phytotoxicity symptoms were observed.

The results of the greenhouse experiments confirmed the feasibility of the proposed remedial action program. Detailed results of these experiments have been reported (Sopper 1987).

FIELD TRIALS

In May 1986 nine 0.4-ha plots were established along a road bulldozed to provide access to the midslope area of Blue Mountain. The plots were located in sets of three for the application of the three sludge-fly ash mixtures. Because of the low potassium content of the sludge, a potassium supplement equivalent to 90 kg/ha was applied to the plots with the lime. Lime was applied at 22 Mg/ha which was double the amount required to raise pH to 7.0 based on a soil analysis. The lime was applied at this higher rate because of the extremely high concentrations of trace metals in the black humus detritus material that sporadically covers large areas. The lime and potash were applied to the plots using an Estes "Aerospreader" truck.

The application rates for the sludge-fly ash mixtures were determined on the basis of previous research results using sludge to revegetate barren strip mine land (Seaker and Sopper, 1984). From that research it was found that successful vegetation establishment was assured if the sludge were applied at a rate sufficient to supply a minimum of 1,120 kg of total nitrogen per hectare. Because of the high N concentration in the Allentown sludge only about 22 Mg/ha would have to be applied to supply 1,120 kg N per hectare. However, this amount would not provide sufficient depth of growing medium to support vegetation. Therefore, it was decided to double the application rate. This application rate would create a large enough pool of nutrients (N and P) to sustain vegetation growth for at least 3 to 5 years.

As a result of the severe erosion, the site is very rocky with fairly large boulders with only a small amount of mineral soil exposed in the interstitial space. A previous survey was made in the vicinity of the field plots to determine the percentage of interstitial space available for vegetation establishment. The average percentage of interstitial space was 53 percent and ranged from 31 to 71 percent. This means that, on the average, only about one-half of each hectare is available for amendment application and vegetation establishment.

Amendment Applications

Typical chemical analyses of the sludge and fly ash used in this project are given in table 1. These are the average values for several composite samples collected as the products were unloaded at the storage area at the base of Blue Mountain. The two amendments were mixed at the storage area with a front-end loader and applied to the plots with an Estes "Aerospreader" truck. The amounts of chemical constituents applied with each mixture is given in table 2. These values were calculated from analyses of samples collected during application of the mixtures to the plots. The amounts of trace metals applied in all mixtures were well below the allowable maximum amounts recommended by the Pennsylvania Department of Environmental Resources for mine land reclamation. The maximum allowable lifetime trace metal loading rates are as follows:

Element	Amounts(kg/ha)
Zn	224
Cu	112
Pb	112
Cr	112
Ni	22
Cd	3

Each field plot was subdivided into five subplots for hydroseeding of five different seed mixtures. All field plots were mulched with CELLIN fiber mulch at an approximate rate to 2,240 kg/ha. Mulch was applied with a hydroseeder. Results of the herbaceous vegetation growth responses are described by Oyler elsewhere in these Proceedings.

Ten species of tree seedlings were then planted on the field plots during the period June 2-5, 1986. Five seedlings of each species except hybrid poplar were

Table 1.--Typical chemical analyses of the sludge and fly ash used on experimental field plots on Blue Mountain, PA.

Constituent	Sludge Concentration[1]	Fly Ash Concentration[1]
	--%--	--mg/kg--
Total P	1.06	70
Total N	3.59	--
NH_4-N	0.45	--
Org-N	3.14	--
Ca	5.10	5240
Mg	0.35	72
Na	0.12	88
K	0.23	211
Al	1.99	23
Fe	2.94	25
B	--	12
	--mg/kg--	
Mn	839	2.5
Zn	1763	15
Cu	747	3.8
Pb	154	1.2
Cr	379	43
Ni	94	0.3
Cd	9	0.2
Hg	1.4	--
Solids (%)	23	--
Soluble Salts (mhos x 10^5)	--	227

[1] The pH was 8.3 for the sludge, and 8.9 for the fly ash.

Table 2.--Sludge-fly ash mixture application rates and amounts of chemical constituents applied per hectare.

Constituent	(kg/ha) 1S:1FA*	 2S:1FA**	 3S:1FA***
Total P	1214	1120	991
Total N	2455	3030	2735
NH_4-N	282	297	314
Org-N	2172	2733	2421
Ca	5419	5466	3563
Mg	620	626	326
Na	197	148	101
K	1157	560	401
Al	9878	4791	3700
Fe	10131	6635	3939
Mn	43	464	26
Zn	100	109	59
Cu	68	83	53
Pb	26	19	16
Cr	46	39	34
Ni	22	18	10
Cd	0.9	0.9	0.8
Hg	0.1	0.1	0.1

$$\frac{\text{1S:1FA*}}{\text{47 dtS + 235 dtFA}} \qquad \frac{\text{2S:1FA**}}{\text{47 dtS + 117.6 dtFA}}$$

235 wtS + 235 dtFA

235 wtS + 117.6 dtFA

$$\frac{\text{3S:1FA***}}{\text{47 dtS + 78 dtFA}}$$

235 wtS + 78 dtFA

planted on two of the replications of each sludge-fly ash mixture; ten hybrid poplar cuttings were planted on each plot. Tree seedling survival rates in 1986 were poor and were probably due to the late planting date. The seedlings were delivered in April and had to be kept in cold storage until June. As a result, some of the seedlings suffered desiccation, particularly the coniferous species. Early observations two weeks after planting indicated that many of the coniferous species never burst their terminal buds indicating that they were probably dead when planted. Evaluation of the 1986 planting has been reported by Sopper (1987).

In 1987 tree seedlings were again obtained from the Pennsylvania Bureau of Forestry nursery for planting on the field plots. Species planted are shown in table 3. The seedlings were planted during the period May 2-3, 1987. Seven seedlings of each species except hybrid poplar were planted on each field plot; ten cuttings of hybrid poplar were planted on each plot.

RESULTS

Survival and Height Growth

Survival counts and height growth measurements were made on September 10, 1987. Results are given in tables 3 and 4. The highest rate of survival (80%) for all species was found on the 2S:1FA amendment. Species survival ranged from a low of 44 percent for Virginia pine to 91 percent for European alder. Species with the highest survival rates across all amendments were alder (91%), black locust (86%), black cherry (84%), white pine (83%), larch (81%), and hybrid poplar (77%).

Table 3.--Percentage tree seedling survival by amendment mixture.

Species	1S:1FA	2S:1FA	3S:1FA	All Treatments
White Pine	86	79	86	83
Austrian Pine	79	93	57	76
Virginia Pine	50	50	33	44
Red Pine	36	79	57	57
Larch	86	79	79	81
Black Locust	93	100	65	86
Arnot Bristly L.	64	79	65	69
Alder	72	100	100	91
Black Cherry	93	72	86	84
Sugar Maple	79	72	79	77
Hybrid Poplar	100	75	55	77
All Species	76	80	69	

Table 4.--Tree seedling height growth.

Species	1S:1FA	2S:1FA	3S:1FA	All Treatments
	--------------cm-------			
White Pine	19	15	19	18
Austrian Pine	24	17	20	20
Virginia Pine	14	18	21	17
Red Pine	17	19	17	17
Larch	34	28	58	40
Black Locust	55	49	39	47
Arnot Bristly L.	46	35	46	42
Alder	59	53	46	52
Black Cherry	52	57	61	57
Sugar Maple	34	39	38	37
Hybrid Poplar	34	27	52	38
All Species	35	32	38	

There was little difference in average height growth within a species among the three amendments. Larch had the best height growth (40 cm) of the coniferous species, and black cherry had the best height growth (57 cm) of the hardwood species. The two species which exhibited the most vigorous growth were larch and alder.

Foliar Analyses

Foliar samples were collected on September 10, 1987, from all tree species and analyzed for nutrients (N-P-K), cations (Ca and Mg), and trace metals (Mn, Fe, Al, B, Cu, Zn, Pb, Cd, Ni, Co, and Cr). Nitrogen concentrations in the coniferous species ranged from 1.00 to 1.70 percent and in the hardwood species from 1.34 to 3.34 percent across all amendments. In general, the hardwood species had higher concentrations of nutrients and cations than the coniferous species. The results show a slight trend toward increases in nutrient concentrations with increasing amounts of sludge in the sludge-fly ash mixture. Within a species there was little difference in nutrient and cation concentrations among the three amendment mixtures.

Results of the foliar analyses for trace metal concentrations are given in table 5. Due to limited space, data are presented only for the potentially most toxic elements and selected species. Foliar concentrations of Cu, Ni, Cr, and Co were under the suggested tolerance level for all tree species on all amendments. The suggested tolerance levels are not phytotoxic levels but suggest foliar concentration levels at which one may expect to get decreases in growth (Melsted 1973). Similarly, foliar B concentrations were all below the suggested tolerance level for all tree species on all amendments except for black locust on the 1S:1FA mixture. Foliar Mn concentrations were all below the suggested tolerance level except for white pine on all three amendments and alder on the 2S:1FA mixture. Foliar Pb concentrations exceeded the suggested tolerance level in all species on all amendments. The highest foliar Pb concentration was 140 mg/kg in alder. Lead toxicity should not be a problem since Rolfe (1973) reported that leaf Pb concentrations from 40 to 90 mg/kg did not produce any phytotoxicity symptoms in some of the same species planted on this project. Foliar Cd concentrations equalled or exceeded the suggested tolerance level in all species on all amendments. Hybrid poplar had the highest Cd concentrations while alder and black cherry had the lowest concentrations. In general, within a species there was little difference in foliar trace metal concentrations among the three amendments. No phytotoxicity symptoms were observed on any species.

SUMMARY AND CONCLUSIONS

A field plot study was conducted to evaluate the feasibility of using mixtures of sludge and fly ash as amendments to facilitate the reforestation of a highly contaminated site at a zinc smelter in Palmerton, PA. Three mixtures of sludge (S) and fly ash (FA) were applied to 0.4-ha field plots in May 1986. The mixtures on a volume basis were 1S:1FA, 2S:1FA, and 3S:1FA. Seedlings of 10 tree species were planted in June 1986 and seedlings of 11 tree species were planted in May 1987. Measurements of survival and height growth were made each year. Foliar samples were collected at the end of the growing season for analyses for nutrients and trace metals concentrations. While seedling survival in 1986 was poor, primarily due to the late planting date, survival in 1987 was excellent. Species survival ranged from 44 to 91 percent across all three amendments. The highest survival rate (80%) for all species was found on the 2S:1FA amendment. Within a species there was little difference in average height growth among the three amendments. Larch and black cherry had the best height growth. Foliar concentrations of Cu, Ni, Cr, Co, and B were generally below the suggested tolerance level for growth suppression in all species on all three amendments. Foliar concentrations of Mn, Fe, Al, Zn, Pb, and Cd were all above the suggested tolerance level in most species on all three amendments. However, no phytotoxicity symptoms were observed on any species. Results indicate that all three sludge-fly ash mixtures were successful in facilitating tree seedling establishment on the highly contaminated soil. Monitoring of tree seedling survival and growth will continue for several years. However, while the research will continue, plans are being formulated to continue to apply the sludge-fly ash amendment to additional areas on Blue Mountain. It is anticipated that it will take about five years to revegetate the entire 800 ha.

Table 5.--Effects of sludge-fly ash amendments on selected trace metal concentrations in the foliage of tree seedlings.

Tree Species	Amendment Mixture	Mn	Cu	B	Zn	Pb	Cd	Ni
		mg/kg						
White Pine	1S:1FA	947	14	56	700	40	14	4
	2S:1FA	791	13	47	840	31	6	4
	3S:1FA	732	13	33	604	49	14	4
Larch	1S:1FA	103	7	66	408	34	6	3
	2S:1FA	170	8	84	402	33	5	3
	3S:1FA	159	7	71	450	42	4	3
Black Locust	1S:1FA	103	12	104	870	88	11	6
	2S:1FA	168	12	81	430	59	7	6
	3S:1FA	121	12	72	470	47	12	6
Alder	1S:1FA	154	25	57	1258	140	5	7
	2S:1FA	441	20	58	807	104	4	7
	3S:1FA	164	21	56	2070	76	3	10
Black Cherry	1S:1FA	121	12	29	1033	99	7	5
	2S:1FA	215	11	34	887	84	6	3
	3S:1FA	170	9	28	490	53	4	4
Hybrid Poplar	1S:1FA	106	9	64	1605	34	32	3
	2S:1FA	179	10	34	1650	70	27	4
	3S:1FA	89	10	47	4000	28	66	4
Suggested Tolerance Level		300	150	100	300	10	3	50

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Liriodendron Seedling Growth on Calcareous and Acid Minesoils Developed under Pine or Hardwood[1]

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Abstract.--We tested effects of two parent materials, two slope positions, and four tree species on growth and mineral nutrition of tuliptree seedlings. We grew the seedlings for 17 weeks in cores of acid (pH 3.7) or calcareous (pH 7.2) minesoil collected under white pine (*Pinus strobus* L.), black locust (*Robinia pseudoacacia* L.), white ash (*Fraxinus americana* L.), or tuliptree (*Liriodendron tulipifera* L.) that had been planted by the U.S. Forest Service in 1946 on ungraded, unfertilized coal spoils. In 1977, we collected cores of soil near the top or bottom of the small, steep-sided hillocks and planted tuliptree seedlings in these cores. Seedlings grown in black locust soils were taller, with heavier leaves, stems and root systems than those grown in other minesoils, while seedlings grown in white pine soils were smaller and lighter than all the others. Effect of slope position depended on parent material; on the acid minesoil, seedlings grown in soil from the lower slope position were taller, with heavier leaves and root systems, but on the calcareous minesoil, slope position had the opposite effect. The acid minesoil produced larger, heavier seedlings than the calcareous one. Black locust soils produced seedlings with leaf blades higher in N and P and lower in Mg than those developed under the other 3 species. Leaf blades of seedlings grown in white pine soils were lowest in P and K. Seedlings grown in acid minesoil had higher concentrations of N, P, K, Mg. and Mn, and lower concentrations of Ca in their leaf blades than those grown in calcareous minesoil. Possible reasons for difference in seedling growth include more favorable physical properties in the acid minesoil or micronutrient deficiciencies in the calcareous minesoil.

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INTRODUCTION

As coal production by surface mining increased during World War II, miners and conservation agencies recognized the need for reclaiming coal spoils to restore productivity and to reduce off-site damages. In 1946 the U.S. Forest Service, in cooperation with several coal companies, established a number of experimental plantings throughout the eastern Ohio coal fields (Limstrom and Merz, 1949; Finn, 1958; Limstrom, 1960; Larson and Vimmerstedt, 1983). White pine, black locust, tuliptree and white ash were among the species planted at 7 x 7 foot spacings in 105 x 105 foot blocks on both calcareous and acid minesoils. Thirty-one years later, we compared growth and mineral nutrition of tuliptree seedlings planted in soils that had developed under these four species on the two contrasting parent materials (Jewell, 1978). We also tested the effect of slope position by growing the seedlings in soil collected from the top or bottom of the ungraded spoil banks. Our objectives in this greenhouse experiment were to determine the effects of the following soil-forming factors: parent material, organisms and topography, on growth and mineral nutrition of tuliptree seedlings. In particular, we wanted to find out how tuliptree seedlings performed on soil developed under black locust because of the large acreage of coal spoils revegetated with black locust that were subsequently attacked and rendered unproductive by locust borer (*Megacyllene robiniae*).

MATERIALS AND METHODS

In this study we used undisturbed cores of soil obtained by forcing number 10 tin cans into the soil until the can was flush with the top of the litter, as described by Clark (1963). Cans were excavated and removed to a greenhouse. Plantings from which cores were removed were on ungraded, unlimed and unfertilized minesoils created by surface mining from 1941 to 1944.

Calcareous minesoils near Cadiz, Ohio were produced in 1943-44 by shovel stripping the Pittsburgh coal seam. Overburden consisted of acidic shale, calcareous shale, and limestone, with limestone predominating. Upon disintegration and settling, these materials formed tight, impervious, poorly aerated spoil banks (Limstrom, 1946a) which are presently classified as Morristown stony clay loam, a loamy-skeletal, mixed calcareous, mesic Typic Udorthent (Rubel et al., 1981). At planting these minesoils were 90% barren, with scattered plants of red clover (*Trifolium pratense*), wild carrot (*Daucus carota*), common plantain (*Plantago* spp.), thistle, pepperweed (*Lepidium* spp.), bluegrass (*Poa* spp.), sweetclover (*Melilotus* spp.), dandelion (*Taraxacum*), elderberry (*Sambucus* spp.) and dead ragweed (*Ambrosia bidentata*) (Limstrom, 1946a). In 1976, pH of this soil averaged 7.1, with 69% of the soil particles less than 2.0 mm in diameter.

Acid minesoils south of Dundee, Ohio were produced in 1941-42 by mining the Lower Kittanning coal seam. Grayish black shale predominated in the overburden, with some sandstone. Minesoil at this site is classified as Bethesda silty clay loam, a loamy-skeletal, mixed acid Typic Udorthent (L. A. Tornes, Assistant State Soil Scientist, U.S.D.A. Soil Conservation Service, personal communication). At planting time, the spoil surface varied from shaly sand to stony sand, with soil pH ranging from 3.8 to 5.5, and with little or no natural vegetation (Limstrom, 1946b). In 1976, soil pH averaged 3.7, with 61 percent of the soil particles less than 2.0 mm in diameter.

On each parent material, we randomly selected 3 trees of each species growing on upper and lower slope positions. Soil cores were removed under each tree in the 4 sectors midway between the trunk and the edge of the crown. With 2 parent materials, 4 tree species, 2 slope positions, 3 trees per slope position and 4 cores per tree, a total of 192 cores were involved in the experiment. Soil cores, with plastic film at the bottom to prevent free drainage, were arranged in the greenhouse in a completely randomized design, and re-randomized half way through the experiment.

Two newly-germinated tuliptree seedlings were transplanted into each core on May 16 and grown under natural light until September 7. Cores were watered every third day with deionized water; the amount was adjusted periodically by weighing randomly-selected cores and estimating the amount of water required to restore them to their weight at time of collection.

At harvest, we measured total seedling height from cotyledon to tip of terminal bud. Leaves were counted and leaf blades, petioles and stems of each seedling were dried for 3 days at 60° C. Roots of the seedlings were washed free of soil and also dried at 60° C. Dry weights of seedling parts were determined.

Nitrogen concentration in leaf blades was determined by Kjeldahl analysis, and P, K, Ca, Mg and Mn were determined by inductively coupled plasma emission spectrometry. We combined plant tissue from the two upslope and two downslope soil cores (4 seedlings) in order to have sufficient material for tissue analysis.

Data subjected to analysis of variance included seedling heights, weights of leaf blades, leaf petioles, stems and roots, number of leaves per seedling and concencration of N, P, K, Ca, Mg and Mn in leaf blades. Means of the physical measurements of the two seedlings in each core were used as data entries in the statistical analysis. When analysis of variance showed statistically significant effects at $p=0.05$, Duncan's mean range test was used for mean separation.

RESULTS

Tuliptree seedlings grown in soils collected under black locust were taller, heavier and had more leaves than those grown in soils from under tuliptree, white ash or white pine. Seedlings grown on white pine soils were smallest (table 1). The effect of slope position on seedling size varied with parent material. On the acid minesoil, soils from the lower slope positions produced the tallest, heaviest seedlings but on the calcareous minesoils, soils from the upper slope positions had the tallest, heaviest seedlings (table 1). In the case of stem weight, the

Table 1.--Height, number of leaves, petiole, blade, stem and root weights of tuliptree seedlings grown for 17 weeks in undisturbed soil cores collected at upper or lower slope positions under 4 tree species on acid or calcareous minesoils.

	Total Height	Total		Oven Dry Weight		
			Blades	Petioles	Stem	Root
	(cm)	(no)	----------------g-----------------			
Species[1/]						
Black Locust	15.3^{a}	10.2^{a}	1.19^{a}	0.15^{a}	0.73^{a}	2.03^{a}
Tuliptree	12.6^{b}	9.0^{b}	0.95^{b}	0.12^{b}	0.59^{b}	1.93^{a}
White Ash	11.7^{bc}	8.6^{b}	0.85^{bc}	0.10^{bc}	0.50^{bc}	1.92^{a}
White Pine	10.3^{c}	8.5^{b}	0.74^{c}	0.09^{c}	0.43^{c}	1.58^{b}
Parent Material x Slope Position Interaction						
Acid						
Upper Slope	12.76^{b}	9.4^{ab}	0.96^{b}	0.12^{b}	0.59^{b}	1.89^{b}
Lower Slope	17.06^{a}	9.8^{a}	1.26^{a}	0.16^{a}	0.81^{a}	2.42^{a}
Calcareous						
Upper Slope	11.07^{b}	8.8^{bc}	0.86^{b}	0.10^{b}	0.50^{b}	1.76^{b}
Lower Slope	8.94^{c}	8.3^{c}	0.64^{c}	0.08^{c}	0.35^{c}	1.39^{c}

[1/] Within each column, means with a common superscript letter do not differ significantly at the 5% level, Duncan's Mean Range Test.

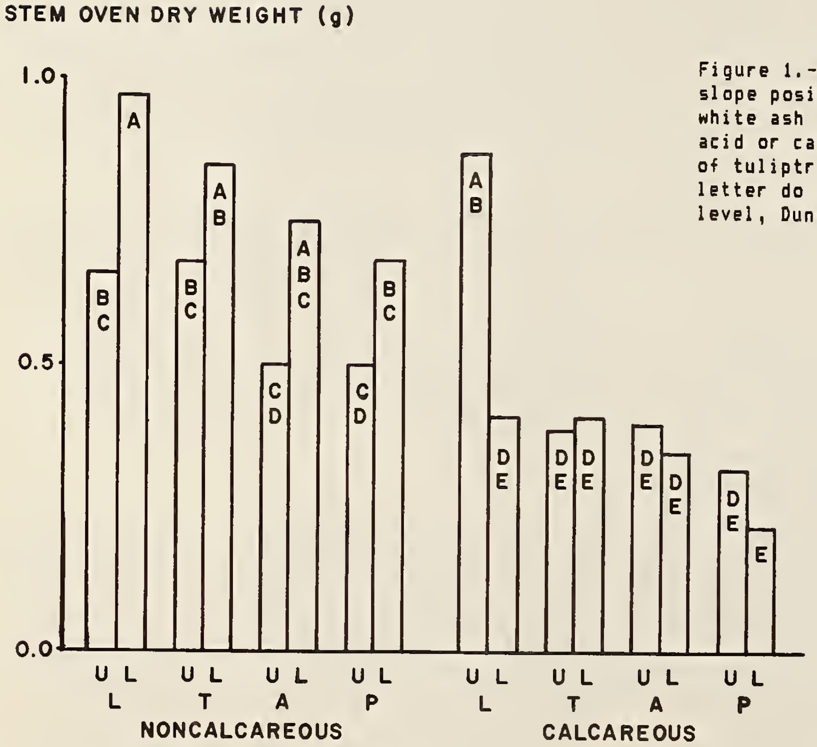

Figure 1.--Interaction of upper (U) or lower (L) slope positions, black locust (L), tuliptree (T), white ash (A) or white pine (P) tree species and acid or calcareous parent material on stem weight of tuliptree seedlings. Bars containing a common letter do not differ significantly at the 5% level, Duncan's Mean Range Test.

Table 2.--Concentrations of N, P, K, Ca, Mg and Mn in leaf blades of tuliptree seedlings grown for 17 weeks in undisturbed soil cores collected at upper or lower slope positions under 4 tree species on acid or calcareous minesoil.

	N	P	K	Ca	Mg	Mn
	%					ppm
Species[1/]						
Black Locust	1.91^{a}	0.22^{a}	1.50^{a}	1.23	0.28^{b}	405
Tuliptree	1.49^{b}	0.19^{b}	1.49^{a}	1.36	0.37^{a}	378
White Ash	1.51^{b}	0.19^{b}	1.53^{a}	1.34	0.38^{a}	352
White Pine	1.50^{b}	0.17^{c}	1.28^{b}	1.42	0.37^{a}	388
Parent Material[1/]						
Acid	1.66^{a}	0.22^{a}	1.57^{a}	1.00^{b}	0.38^{a}	729^{a}
Calcareous	1.54^{b}	0.17^{b}	1.33^{b}	1.67^{a}	0.33^{b}	32^{b}

[1/] Within each column, means with a common superscript letter do not differ significantly at the 5% level, Duncan's Mean Range Test.

Table 3.--Interaction of tree species and parent material on potassium concentrations in leaf blades of tuliptree seedlings grown for 17 weeks in undisturbed cores of eastern Ohio minesoils.

	Parent Material	
	Acid	Calcareous
	Potassium Concentration (%)	
Species[1/]		
Black locust	1.56^{bc}	1.45^{cd}
Tuliptree	1.69^{ab}	1.28^{de}
White Ash	1.80^{a}	1.26^{de}
White Pine	1.23^{e}	1.32^{de}

[1/] Means with a common superscript letter do not differ significantly at the 5% level according to Duncan's Mean Range Test.

species x slope position x parent material interaction was significant (figure 1). Stem weights of seedlings from upper slope, calcareous soils under black locust differed from all others grown on calcareous soils and were almost as heavy as the heaviest grown on acid soils.

Nitrogen and phosphorus concentrations in leaf blades of seedlings grown in black locust soils were higher than in those from tuliptree, white ash or white pine, while magnesium concentrations were lower (table 2). Concentrations of P were lowest in leaf blades of seedlings grown in white pine soil. Concentrations of N, P, K, Mg and Mn were higher in leaf blades of seedlings grown on the acid soils; Ca concentrations were lower (table 2). There was a significant species x parent material interaction on potassium concentration of leaf blades, with those grown on soils from under tuliptree or white ash higher in the acid spoils than in the calcareous ones, while potassium concentrations did not differ significantly with parent material on locust or pine soils.

DISCUSSION AND CONCLUSIONS

Tuliptree is a demanding species in terms of nutrient requirements. If we consider tuliptree seedling growth to be a bioassay of soil quality, then we conclude that black locust was the most effective tree species for improving soil conditions on these ungraded, unfertilized coal spoils, and that white pine was least effective. Reasons for superiority of soils developed under black locust appear to be availability of nitrogen and phosphorus, with nitrogen availability probably the overriding factor. In a related study, soils that developed under black locust were higher in total nitrogen than those that developed under tuliptree, white ash, or white pine (Vimmerstedt et al., in press).

Of the two parent materials, the acid shales and sandstones produced larger, more nutrient-rich seedlings than the limestone. Availability of N, P and K was evidently greater in the acid minesoils, but the friable nature of the shale-derived soils, contrasted to the impervious nature of the calcareous soils, may have been an additional factor promoting greater growth on the acid parent materials. At the high pH of the calcareous minesoil, micronutrient deficiencies are an additional possible explanation for the relatively poor growth.

Because of its rapid early growth, nitrogen-fixing ability and potential for yielding valuable posts and poles, black locust was a popular early choice for reforesting coal spoils. Although locust borer attacks prevented growth of saleable products, black locust plantings were effective in soil improvement, and have paved the way for establishment of productive stands of succeeding species. Furthermore, more volunteer trees were found in black locust plantings than in those of white ash, white pine or tuliptree (Larson, 1984). White pine, although quite effective in producing a protective litter layer, was the least effective of the four species in creating favorable soil conditions for growth of tuliptree seedlings.

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A CHRONOSEQUENCE OF VEGETATION AND MINESOIL DEVELOPMENT ON A TEXAS LIGNITE SURFACE MINE[1]

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Abstract.--Unreclaimed mined sites ranging in age from 1-50 years were sampled to evaluate vegetation and minesoil changes with time, and compared to an adjacent unmined area. One-year-old, unreclaimed mined areas had very sparse vegetation dominated by weedy species. Herbaceous plant cover increased on mined areas that were 5, 10, and 15 years old, and reached a peak on 20-year-old mined sites. On mined sites older than 20 years, shrub and tree canopies began suppressing understory species. Shrub and tree species were observed on mined areas as early as 5 years after mining, but shrub and tree cover did not become substantial until 20 to 30 years after mining. A multi-layered tree and shrub vegetation structure dominated the 50-year-old site. Compared to native soils of the area, minesoil pH increased from 5.9 to 6.9 shortly after mining then dropped to 3.8 during the next 5 years due to weathering and release of acidic ions. Continued weathering and pyrite oxidation caused minesoil pH to remain at this level for approximately 30 years. Minesoil pH of the 50-year-old site was 6.8. Bulk density of minesoils in the surface 12 cm declined with time as vegetation, litter, and organic matter increased on the site. A similarity index revealed the intermediate-aged mined sites (5, 10, 15, and 20) were similar in plant species composition. Vegetation establishment and development on these different-aged mined sites followed several models of ecological succession: initial floristics model (plants reach disturbed areas as a result of chance and remain until other plant species become more competitive for resources), tolerance model (each individual plant species possesses characteristics or mechanisms which make it adapted to the site), and relay floristics (some plants ameliorate the site and fascilitate establishment by other species).

INTRODUCTION

Natural plant succession and minesoil development on unreclaimed areas after disturbance have been reported in Minnesota (Leisman 1957), Wisconsin (Kimmerer 1984), Montana (Schafer et al. 1980, Schafer and Nielsen 1979, Sindelar 1979), Iowa (Glen-Lewin 1979), Illinois (Croxton 1928), Indiana (Byrnes and Miller 1973), Ohio (Bell and Ungar 1981), Pennsylvania (Bramble and Ashley 1955, Brenner et al.

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1984), West Virginia (Smith et al. 1971), Kentucky (Thompson et al. 1984), Missouri (Game et al. 1982), and Oklahoma (Gibson et al. 1985, Johnson et al. 1982). Most of these studies have attempted to evaluate the plant species and communities that established and developed on the disturbed area, and to assess the influence of soil properties on plant community development.

The Sandow Mine in Milam County, TX, began surface mining for lignite in 1918. The mining operation closed in 1920, reopened in 1924, and closed again in 1948. The mine was reopened by the Aluminum Company of America in 1953 and has continued to mine lignite to the present day. A number of areas on the Sandow Mine were mined during the past several decades prior to the enactment of State (Texas Surface Mining and Reclamation Act of 1977) and Federal (U.S. Surface Mining Reclamation and Control Act of 1977) regulations, and were undergoing natural revegetation.

The plant communities that established and developed on these unreclaimed mined areas provide an example of primary succession in which the major limiting factors are edaphic. Typically, minesoils resulting from lignite mining in the Post Oak Savannah vegetation region in Texas are characterized by a pH of 4.0 to 6.0, a high percentage of silt and clay particles, low amounts of organic matter, low levels of nitrogen and phosphorus, and low populations of microorganisms (Dixon et al. 1980). Minesoil characteristics are often extremely variable, both between and within spoil piles, and consequently the associated vegetation can be quite variable.

To date, no study of plant species composition, community structure, and minesoil properties has been conducted on different-aged, unreclaimed lignite mined areas in Texas. The objectives of this study were to evaluate the minesoils and the vegetation that naturally established on a series of different-aged mined areas and compare them to an adjacent unmined area.

MATERIALS AND METHODS

Study Site

The Sandow Mine is located in the Post Oak Savannah vegetation area of east-central Texas. The climate is moderately humid, subtropical, and continental. Mean annual precipitation is 90 cm irregularly distributed with May and October peaks. Summer drought is common.

Native vegetation in this area is dominated by post oak (Quercus stellata Wang.), winged elm (Ulmus alata Michx.), eastern redcedar (Juniperus virginiana L.), greenbriar (Smilax bona-nox L.), yaupon (Ilex vomitoria Ait.), and numerous grasses and forbs. Grasses which commonly occur in this area are little bluestem (Schizachrium scoparium (Michx.) Nash), switchgrass (Panicum virgatum L.), brownseed paspalum (Paspalum plicatulum Michx.), Texas wintergrass (Stipa leucotricha Trin. & Rupr.), and deertongue (Dichanthelium clandestinum (L.) Gould) (Gould 1975).

Native soils in this region are predominantly fine sandy loams or loamy fine sands over clayey subsoils. The soils are generally infertile with low amounts of organic matter. Several soil series are prevalent in this area including Axtell fine sandy loam (Udertic Paleustalfs), Rader fine sandy loam (Aquic Paleustalfs), and Uhland loam (Aquic Ustifluvents). Shales in the overburden associated with lignite seams contain acid-producing (pyritic sulfur) as well as calcareous materials.

Methods of mining lignite on this site over the past 50 years vary considerably. The authors are unsure of the machinery that was available and operating in the 1930's at the site. However, several of the older workers on the site explained that small shovels were used and these shovels could be observed on the site among old machinery. These shovels were small with bucket capacities of 2 to 4 m^3 (3 to 5 cu. yd.) and were probably used during the 1930's and 1940's. Shovels and backhoes with buckets ranging from 6 to 12 m^3 (8 to 16 cu. yd) were used on the site in the 1950's and 1960's. Draglines with 29 m^3 (38 cu. yd.) buckets were used on the site in the 1970's, while much larger draglines (72 m^3 or 95 cu. yd) were employed in the late 1970's, and their use on the site continues to the present. The different equipment used for overburden removal is important because it influenced the size of the spoil piles. These old, mined areas were not graded or seeded and the plants and plant communities establishing on these unreclaimed sites are a result of invasion and primary succession.

Sampling Methods and Analysis

Seven ungraded, unreclaimed areas, which were mined in different years, were chosen based on mining date and proximity to each other. The selected areas were mined in 1933, 1953, 1963, 1968, 1973, 1978, and 1983. Representative portions within each mined area were sampled in May and June 1983. On each area, nine 30-m transects were placed perpendicular to the spoil pile slope: three transects were located at the base, three along the side, and three at the top of the spoil pile. Herbaceous species were identified and assigned cover and density values in a 50-cm wide by 50-cm long (0.25 m^2) quadrat placed at 3-m intervals along the transect line. Herbaceous biomass was clipped at ground level, separated into grass and forb components, and placed into labelled paper bags. The plant material was dried at 60°C for 48 hr and weighed to determine dry weight. Total plant cover, litter cover, and bare ground were also estimated in each 0.25-m^2 quadrat.

Woody plant cover was determined by the line-intercept method along the 30-m transects. Every tree and shrub species that intercepted the transect line was identified and its canopy coverage over the transect line was measured.

Soil samples were taken to a depth of 25 cm at two points along each transect line and composited. Samples were also taken at these same two points to determine bulk density using the core method to a depth of 12 cm (Blake and Hartge 1986). Soil samples were analyzed for pH (2:1 water-soil paste), water soluble salts, and several macronutrients. Phosphorus, potassium, calcium, and magnesium were extracted by $NH_4OAc\text{-}HCl\text{-}H_4EDTA$ and analyzed by atomic absorption (Welch et al. 1980).

Data were analyzed by the Statistical Analysis System (SAS). Analysis of variance was conducted to determine differences in vegetation and soils across different-aged mined sites and the means were separated by Duncan's multiple range test (Ray 1982).

RESULTS AND DISCUSSION

Vegetation

Sparse vegetation was found on 3-month and 6-month-old mined sites in Texas (table 1). A few invading forb and grass species (*Aster*, *Amaranthus*, *Chenopodium*, *Polygonum*, *Dichanthelium*) were observed. On the 6-month-old site, the number of plant species increased threefold (table 2), even though they were still sparse. These plants established first in patches, possibly due to better minesoil or microenvironmental conditions, or due to the presence of seed and/or rhizome banks in the minesoil. The vegetation patches grew on minesoils that had a lighter color than adjacent darker bare areas. The lighter colored minesoil was probably part of the original oxidized zone in the soil and overburden, and was already partially weathered. The color of the minesoil may also have influenced the amount of solar radiation that was absorbed or reflected, thereby affecting minesoil temperature. Samples were collected from light and dark minesoils and analyzed. The only difference that was evident in our limited analysis was the darker minesoil had a high soluble salt content (550 mg/kg) versus no measureable salt content on the lighter minesoils.

According to Game et al. (1982), unreclaimed surface mines in Missouri were colonized initially by invading plants which grew to form patches and these patches gradually enlarged, coalesced, and covered the surface. We observed a similar trend on mined sites in Texas that were 1, 5, 10, and 15 years old. Even though data are not presented on the cover differences between tops, sides, and bottoms of minesoil piles, a general observation should be made. Sides and tops of the minesoil piles of all ages had lower plant cover than the bottoms. This was likely due to slope steepness, and to the

Table 1--Herbaceous vegetation characteristics of eight different-aged, unreclaimed minesoils and an adjacent unmined area.

Age of Minesoil	Total Herbaceous Plant Cover	Litter Cover	Bare Ground	Average Number of Species in Quadrat		Grass Biomass	Forb Biomass
				Grasses	Forbs		
	%					kg/ha	
3 months	0.1 d[1]	0.1 f	88.6 a	0.1 d	0.0 d	1 c	0 b
6 months	1.3 d	3.1 ef	69.2 b	0.1 d	0.1 d	4 c	2 b
5 yr	12.0 c	6.2 e	77.5 b	0.5 c	0.8 c	215 ab	139 a
10 yr	10.2 c	6.9 e	73.7 b	0.5 c	0.3 c	182 b	36 b
15 yr	12.1 c	9.2 e	72.2 b	0.6 c	0.5 c	218 ab	116 a
20 yr	25.1 b	23.2 d	48.0 c	1.4 a	1.2 b	329 a	153 a
30 yr	14.8 c	40.1 c	42.6 c	1.1 b	1.2 b	196 b	109 a
50 yr	4.2 d	84.1 a	11.1 d	0.4 c	0.5 c	42 c	21 b
Unmined	31.6 a	55.5 b	12.9 d	1.5 a	2.7 a	248 ab	161 a

[1] Values in columns with the same letter are not significantly different a $p<0.05$.

Table 2--Total number of grass, forb, shrub, and tree species observed on different-aged, unreclaimed minesoils and an adjacent unmined area.

Age of Minesoil	Number of Species Observed						
	Grass		Forb				
	Annual	Perennial	Annual	Perennial	Vine and Shrub	Tree	TOTAL
3 month	-[1]	1	2	2	-	-	5
6 month	2	4	4	5	-	-	15
5 yr	3	6	11	13	1	4	38
10 yr	-	12	8	13	7	5	45
15 yr	-	10	3	10	4	3	30
20 yr	1	11	6	13	4	4	39
30 yr	3	5	3	9	7	9	31
50 yr	1	5	1	5	7	9	28
Unmined	1	12	6	13	6	6	44

[1] No species of this type were observed on the site.

instability and slipping of the minesoil at these positions reducing the ability of plant roots to develop. Another likely reason is improved moisture conditions in the bottom of or between the piles due to water runoff and erosion of fine-textured material to the bottom position. Analysis of some chemical properties (pH, P, K, Ca, Mg, and soluble salts) of the minesoil at these three position on each site showed few significant differences.

Herbaceous plant cover continued to increase until reaching a peak on the 20-year-old site (table 1). Understory cover decreased on 30- and 50-year-old mined sites due to shading from tree and shrub canopies (table 3). The average number of grass and forb species occurring in a quadrat on the mined areas was almost always significantly lower than the average number of species in quadrats from the unmined area (table 1). Intermediate-

Table 3--Characteristics of woody vegetation on eight different-aged, unreclaimed minesoils and an adjacent unmined area.

Age of Minesoil	Tree Canopy Cover (%)	Average Number of Tree Species in Transect	Shrub Canopy Cover (%)	Average Number of Shrub Species in Transect
3 months	0	0	0	0
6 months	0	0	0	0
5	0	0	0	0
10	0	0	3.8	0.7
15	0	0	2.0	0.4
20	0	0	13.7	1.6
30	4.0	0.4	30.4	3.4
50	90.6	5.0	82.1	4.5
Unmined	58.0	2.7	6.9	2.5

aged sites (5 to 20 years old) had the highest total number of species per site on mined areas (table 2), and were similar in herbaceous biomass to the unmined site (table 1).

Cover by woody species increased as these mined sites aged (table 3). Shrubs began establishing on the 5-year-old site and continued to increase with 82% shrub cover on the site that had been mined 50 years ago. Several trees were observed on 5, 10, 15, and 20-year-old sites, but the trees were not large or numerous enough to be intercepted by our sampling techniques. On the 30-year-old site, shrub cover began to dominate the site. On the 50-year-old site, a multi-layered plant community had developed with vines, shrubs, and trees. So thick was the vegetation on this 50-year-old site, that movement in the area was difficult.

Minesoil Properties

In most areas in Texas, minesoils generated from lignite overburden have finer, more-favorable textures, increased water and nutrient-holding capacities, and higher productivity potential than adjacent undisturbed sites (Angel 1973, Dixon et al. 1980, Chichester 1983). Clay content in Texas minesoils is generally higher compared to native soils (Chichester 1983) and this can result in a 25% increase in water-holding capacity (Dixon et al. 1980). Bulk density was 1.28 Mg/m^3 on native soils near the Sandow Mine (table 4). After random overburden placement with draglines, the bulk density remained very similar for the following 10 to 15 years after mining. Reductions in bulk density on older mined areas may be due to several factors. First, mining equipment used 20, 30, and 50 years ago was not as large, nor did it dump such large buckets of overburden which may not have compacted the minesoil so much. On the other hand, litter cover was significantly greater on 20-, 30-, and 50-year-old mined areas compared to sites that were mined more recently. The increase in litter cover undoubtedly increased the amount of organic matter and humus in the minesoil and resulted in a lower bulk density compared to recently mined sites. On the 30- and 50-year-old sites, a bulk density of less than 1.00 Mg/m^3 indicates a surface horizon containing high amounts of organic matter.

Soil pH of the unmined site adjacent to the Sandow Mine was 5.9 (table 4). Disturbing and mixing the soil and overburden overlying the lignite seams created a minesoil with a pH of almost 7.0. However, on mined sites from 5 to 30 years old, the pH was in the 3.2 to 4.5 range, while the 50-year-old site exhibited a surface minesoil pH of 6.8. It is not clear why the pH on the 50-year-old site was so high. Information concerning overburden analysis from the permit (submitted in 1975) revealed that pyritic sulfur asociated with the lignite averaged 0.22%. While this is not a high pyritic sulfur value, it can cause some acid to be formed. The mining permit also reports that an occasional thin layer of limestone occurred with the lignite seam, and overburden analysis again confirms a neutralization potential (% $CaCO_3$) average of 1.5%. Mining for lignite 50 years ago was done near the outcrop and where the lig-

Table 4--Selected minesoil characteristics of eight different-aged, unreclaimed minesoils and an adjacent unmined area.

Age of Minesoil	pH	P	K	Ca	Mg	Soluble Salts	Bulk Density (Mg/m^3)
				(mg/kg)			
3 months	6.9 a[1]	16.0 a	187 b	1968 a	482 ab	335 b	1.35 a
6 months	6.9 a	16.2 a	185 b	1940 a	465 ab	374 b	1.30 ab
5 yr	3.8 cd	12.0 ab	112 c	1867 a	355 b	641 b	1.27 ab
10 yr	3.2 d	7.3 b	85 c	2373 a	445 ab	1410 a	1.35 b
15 yr	3.3 d	13.0 ab	87 c	2707 a	448 ab	1417 a	1.22 b
20 yr	4.2 cd	12.0 ab	180 b	1720 a	433 ab	208 b	1.07 c
30 yr	4.6 c	11.7 ab	209 b	2173 a	470 ab	400 b	0.99 c
50 yr	6.8 a	16.5 a	322 a	3260 a	500 a	0 c	0.93 c
Unmined	5.9 b	4.0 b	190 b	1260 a	340 b	0 c	1.28 ab

[1] Values in columns with the same letter are not significantly different at $p<0.05$.

nite was close to the surface. It is probable that the pyrite associated with the lignite near the outcrop was oxidized before disturbance due to the closeness of the lignite seam to the surface. After disturbance, the pyrite in the overburden did not produce acid and the limestone associated with the seam probably raised the minesoil pH to 6.5 or above. As the lignite seam dipped, the lignite was further from the surface, and pyrite was less oxidized or remained in a reduced state. As bigger equipment was used to mine the lignite from greater depths during successive years, the unoxidized pyrite reacted with air and water thereby releasing acid with time, and decreasing minesoil pH on the intermediate-aged mined sites. Down (1975) reported a rapid drop in pH after mining, and as those minesoils continued to age and weather, pH gradually increased.

Phosphorus concentrations were significantly greater on 1-year-old sites compared to the native, unmined soils. Other nutrients (potassium, calcium, and magnesium) showed no distinct trends in our study. Soluble salts were low to nonexistent on native soils, but increased after mining. During the following 10 to 15 years after mining, soluble salts significantly increased in minesoils. Weathering and oxidation of minerals that had been lying in a reduced state in the overburden before mining probably is the reason for increased soluble salt concentration over time after disturbance. Mineral weathering releases ions which may accumulate at the surface. The increase in soluble salts at the surface may also be due to high surface temperatures and evaporation rates which caused a general movement of water with these mobile ions up to the surface. As the minesoils continued to age and with vegetation establishment, surface moisture and temperature conditions were improved, and these ions were not moved to the surface with water evaporation or may have been taken up by plants.

Whether these different-aged mined sites represent a true minesoil and vegetation chronosequence is hard to determine. The minesoils developed on 5, 10, and 15-year-old mined sites appear from our laboratory analysis to be similar in chemical properties, while the minesoils on the 20 and 30 year-old mined sites are similar to each other. The 50-year-old minesoil is different from all other mined areas, and is also quite different from the native soils of the area. An increase in percent base saturation and leaching of sulfate and acidic cations may help explain why the 50-year-old site has such a high minesoil pH.

Table 5 lists the plant species and the areas where each species occurred. Only one grass (Dichanthelium oligosanthes (Schult.) Gould) was common to all sites sampled, while several grasses, forbs, and

Table 5--Listing of plant species occurring on eight, different-aged, unreclaimed, mined sites (1, 5, 10, 15, 20, 30, 50) and the adjacent unmined area (U).

	Scientific name	Sites Occurring							
Grasses									
p[1]	Andropogon glomeratus			10	15	20	30		
p	Andropogon ternarius			10					
p	Andropogon virginicus			10		20			
a	Aristida oligantha					20			U
p	Bothriochloa saccharoides			10	15	20	30		U
p	Bouteloua rigidiseta								U
a	Bromus japonicus		5						
a	Bromus unioloides	1					30		
p	Carex spp.		5			20	30		U
p	Cynodon dactylon	1	5	10	15	20			
p	Dichanthelium linearifolium				15				U
p	Dichanthelium oligosanthes	1	5	10	15	20	30	50	U
p	Digitaria spp.			10					
p	Elymus virginiana							50	
p	Eragrostis spp.					20		50	U
p	Eragrostis sessilispica								U
a	Hordeum pusillum	1							
p	Leptoloma cognatum						30		
p	Lolium perenne	1	5						
p	Panicum brachyanthum			10					
p	Paspalum dilatatum	1	5	10	15	20		50	
p	Paspalum plicatulum			10					U
p	Paspalum setaceum			10	15	20			U
a	Phalaris caroliniana		5				30		
p	Schizachrium scoparium				15	20			U
p	Setaria geniculata		5		15				
p	Setaria leucopila					20			

a	Setaria viridus		5						
p	Sorghum halepense				15			50	
p	Sporobolus spp.			10					U
p	Stipa leucotricha								U
a	Vulpia octoflora						30	50	
Forbs									
p	Asclepias spp.								U
a	Amaranthus retroflexus	1							
p	Ambrosia psilostachya	1	5		15	20	30		U
p	Aster spp.	1	5	10	15	20	30		
p	Apocynum cannabinum		5					50	
p	Baptisia leucophaea			10	15				
a	Brassica spp.								U
p	Cardaria draba								U
a	Cassia spp.			10					
p	Castilleja spp.					20	30		
a	Chenopodium album	1							
p	Circium spp.						30	50	
a	Collinsia violacea					20			
a	Croton capitatus		5			20			U
p	Daucus carota		5			20	30		
p	Desmanthus virgatus		5	10	15				
p	Desmodium spp.			10					U
a	Diotia teres			10					U
a	Erigeron spp.		5	10		20	30		
p	Eupatorium spp.		5	10	15				
a	Euphorbia spp.		5						
p	Gaillardia spp.					20			
a	Gnaphalium spp.			10					
p	Grindelia spp.		5						
a	Helianthus spp.				15				
p	Heterotheca pilosa		5	10		20			U
a	Iva annua		5						
a	Lactuca spp.		5						
a	Lepidium densiflorum	1	5			20	30		
p	Lespedeza virginica	1		10	15				U
p	Liatris spp.		5	10		20	30	50	
a	Linum medium			10					
p	Marrubium vulgare								U
p	Mentha spicata			10					U
p	Oenothera speciosa		5			20			U
a	Oxalis dillenii	1	5	10		20	30	50	U
a	Phytolacca americana			10					
a	Plantago aristata	1	5	10	15				U
p	Polygonum spp.	1		10	15				U
a	Pyrrhopappus spp.		5						
p	Rudbeckia serotina		5			20	30	50	U
p	Rumex acetosella		5	10	15	20	30		
p	Schrankia spp.								U
a	Senecio spp.								U
p	Sesbania drummondii	1							
p	Solanum spp.				15				
p	Solidago rigida					20			
a	Sonchus spp.		5	10		20			U
p	Taraxacum officinale			10	15	20	30		
a	Trifolium subterraneum				15				
p	Verbena halei		5			20		50	U
a	Vicia ludoviciana		5						
Woody Plants									
	Ampelopsis arborea			10					
	Baccharis salicina		5	10	15	20	30	50	
	Bumelia lanuginosa								U
	Campsis radicans							50	
	Carya illinoensis							50	
	Callicarpa americana			10					
	Celtis pallida						30	50	U
	Cissus incisa			10					
	Fraxinus pennsylvanica							50	
	Ilex decidua							50	
	Ilex vomitoria			10	15	20	30	50	U
	Juniperus virginiana			10	15	20			U
	Opuntia compressa			10		20			

Passiflora incarnata					30		
Populus deltoides	5	10	15	20	30		
Prosopis glandulosa						50	U
Quercus nigra						50	U
Quercus stellata		10				50	U
Rhus toxicodendron		10			30	50	U
Rubus trivialis	5	10	15	20	30		U
Salix nigra	5			20	30	50	
Smilax bona-nox			15		30	50	U
Symphoricarpus orbiculatus					30	50	U
Tamarix gallica		10					
Ulmus alata	5					50	
Vitus mustangensis			15	20	30	50	U

---

[1] p=perennial, a=annual

woody plants were found on 5 or more sites. Table 6 shows a similarity index matrix between each pair of sites based on the plant species that are common to the two sites:

$$\frac{2c}{a + b}$$

When comparing 2 different-aged mined sites, a is the total number of plant species on site 1, b is the total species number on site 2, and c is the total number of species that are common to both sites. This index ranges from 0 to 1.0 (Krebs 1978). Plant species were similar among the 5, 10, 15, 20, and 30-year-old sites (index ranges from .34 to .60), with the 20 and 30-year-old sites having the high value between sites relative to plant species composition. Plants observed on the 50-year-old site were species that occurred on other mined sites and were most similar to those found on the 30-year-old site. However, the older mined site supported several tree species not found on other mined areas.

Vegetation Succession

Vegetation establishment and development on these different-aged, unreclaimed, surface-mined sites in Texas followed several models of ecological succession. First, recently disturbed areas were initially colonized by invading herbaceous plants which possess mechanisms for prolific seed production and dispersion, germination during diverse environmental conditions, and establishment on harsh sites. As time passed after disturbance, weathering and oxidation of the material placed on the surface resulted in a release on ions that created acid minesoil conditions. The plants already established on the site must either have the individual capability to tolerate the gradually increasing acidic minesoil conditions or decline. The weathering, acid minesoil has a low capability of supporting most plants which probably inhibited rapid plant invasion and establishment. The species that possessed mechanisms to avoid or tolerate such edaphic conditions established and expanded on the sites thereby further inhi-

Table 6--Species composition similarity index matrix for each pair of different-aged, mined sites (1, 5, 10, 20, 30, 50) and the adjacent unmined site (U).

	Sites							
Sites	1	5	10	15	20	30	50	U
1	--							
5	.34	--						
10	.23	.39	--					
15	.31	.38	.53	--				
20	.26	.55	.48	.49	--			
30	.26	.46	.34	.43	.60	--		
50	.14	.30	.22	.24	.33	.47	--	
U	.13	.29	.38	.38	.46	.35	.39	--

biting invasion by other species. These plants may have ameliorated the minesoil (increased organic matter content, and improved minesoil temperature and moisture conditions) conceivably fascilitating establishment of less tolerant species on the site. With continued time passage, weathering, and leaching, acidic minesoil conditions gradually diminished allowing native plant species an opportunity to reinhabit the site with initial distribution and abundance. Successional models which appear to operate are the initial floristic composition (inhibition) model (Egler 1954, Grime 1979), the tolerance model (Gleason 1926), and the relay floristics (fascilitation) model (Clements 1916).

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PROGRESSIVE CHANGES IN MINESOIL pH OVER THREE DECADES

Walter H. Davidson, W. Clark Ashby, and Willis G. Vogel[1]

Abstract.--Surface minesoils in the Appalachian and Interior Coal Provinces that include a mixture of overburden materials may experience rapid changes of pH in the early years after mining, followed by slow, longer term changes. Reclamation plantings are commonly made on minesoils atypical in pH for the region. The pH's have ranged from extremely acid to moderately alkaline. Subsequent measurements on these plantings, including soil pH, have shown a high degree of regularity in convergence of pH toward values more typical of regional soils. These changes have been most marked for extremely acid soils. The effects of plant cover may be one cause of the long-term changes in pH.

INTRODUCTION

Pedogenesis embodies the concept of changes in soil properties (Jenny 1980). Many of these changes, such as accumulation of clay, are typically linear and nonreversible in the time frame we are reporting. In the Eastern United States, natural soils may slowly become more acidic with development or maturation over time related to the type of parent material and somewhat to the type of vegetation. Parent materials of upland soils usually are not rich in iron and other sulfides.

By contrast, many coal deposits and associated rock types in the overburden have pyritic materials that rapidly contribute to acidity of minesoils (Ashby et al. 1979). The acidification of fresh minesoils is accompanied by a release of large quantities of hydrogen ions, salts, and bases from affected minerals (Struthers 1964). In his classification of minesoils by pH classes, Limstrom (1960) considered that a pH of 4.0 or less generally indicated conditions lethal to most plants. Studies in Pennsylvania have identified several species capable of tolerating minesoil pH 3.5 (Davidson 1979). Some species survived at lower pH's, but vigor was greatly reduced. Struthers (1961) postulated that the high concentration of salts in a fresh minesoil may account for the tolerance that many plants exhibit toward high acidity. Thus, other chemical and physical factors of the different geologic materials may interact with the pH. These interactions could partially explain why the reports by Limstrom (1960) and Davidson (1979) appear contradictory.

Acidic soils often occur in localized "hot spots." The conventional wisdom in the reclamation field is that these acidity conditions improve with the passage of time (Limstrom 1960, Geyer and Rogers 1972, and Lindsay and Nawrot 1981). In this paper we present substantial information on minesoil changes in pH and evaluate the nature of these changes.

MINESOIL CHANGES OVER TIME

Areas barren of vegetation, so called acid spots or "grease" spots if high osmotic values keep them moist in dry periods, usually are attributed to extreme acidity and its effects on solubilities of nutrient and toxic ions. Much information on persistence of acid spots can be gained from aerial photo interpretation. Coal companies routinely have mining operations photographed over a period of years. We examined successive photos following mining of an 858-acre area in Saline County, southeastern Illinois, for light colored, "barren," and presumably acid spots. Obvious disturbances such as roadways or power lines and water bodies were excluded. Spots continuously light colored from 1952 to 1982 totaled 2.3 acres. This compares with 11.5 such acres in 1965 and 184 acres (21 percent of the total) in 1952. Thus, only 1 percent of the area bare in 1952 was still bare 30 years later. There was an exponential decrease in bare areas over the measured period (fig. 1).

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We restudied some of the same plots 30 years later. Four were in the 858 acres evaluated in the aerial photo study. One, when planted, averaged pH 3.4. Thirty years later, it averaged pH 4.7 based on 30 soil auger core samples to a 6-inch depth. Twelve of the 23 plots in this study, including all below pH 6.0, showed an average increase in pH of 1.3 units. Nine plots, initially at pH 6.0 to 8.3, showed a decrease in pH. Whatever the mechanism of these shifts in pH, the most acid soil conditions did not persist (fig. 2). The sites appeared to be converging toward pH values more typical of regional soils.

A lateral comparison was carried out to document pH levels on increasingly older minesoils. Soil samples for pH determination in the laboratory were collected at several depths in different parts of the Saline County mine approximately 6, 12, and 36 years after mining. Both the 6- and 12-year sites were completely bare of higher plants compared to the 36-year sites, all of which had plant species associated with soil acidity such as three-awn grass (Aristida sp.) and poverty grass (Danthonia sp.)

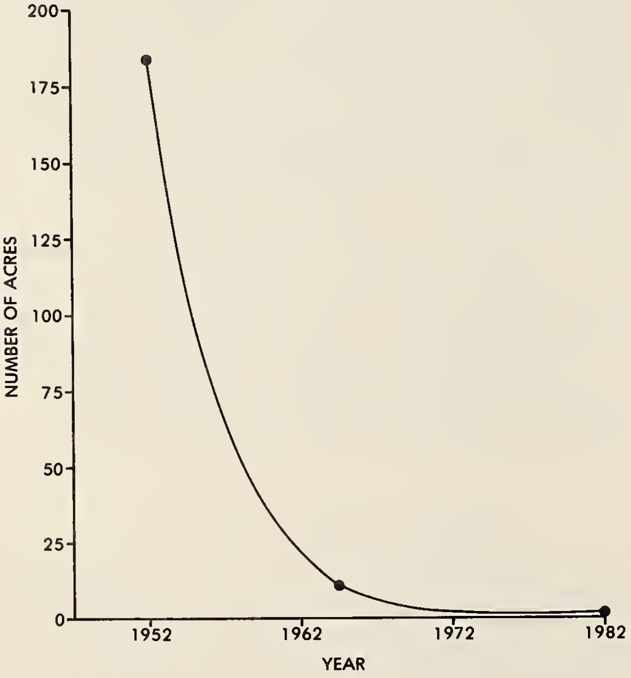

Figure 1.--Changes in acreage exhibiting acid characteristics from 1952 to 1982.

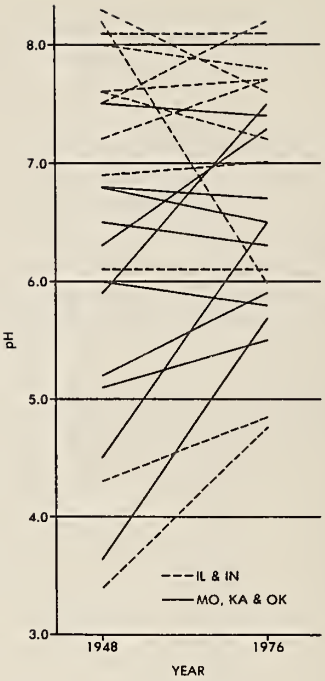

Figure 2. Changes in pH from 1948 to 1976 on 23 plots on midwestern minesoils.

We found that the 6- and 12-year-old acid spots had lower pH than the 36-year site. A futher finding was that the surface pH showed an increasing tendency to be higher than the pH of deeper soil materials with an increase in minesoil age. The significant findings of these studies are that natural processes substantially decreased soil acidity of extremely acid surface minesoils.

Another USDA Forest Service study in which pH data were compared after 19 years showed similar results. In this study, 60 soil samples were collected from a mined site in southeastern Kentucky in 1965 and 1984. Data obtained from the 1965 samples showed that pH averaged 4.2. The 1984 samples averaged pH 4.5. Data from the 2 sample years were segregated into three groups: pH 3.9 and lower, pH 4.0 to 4.9, and pH 5.0 and above. Table 1 shows the changes that occurred over the 19-year period. These figures suggest that the equilibrium pH for this site will be somewhere in the 4.0 to 4.9 range.

Table 1.--Fluctuations in pH on a Kentucky minesoil.

pH Group	1965 Samples	1984 Samples	No. of Samples Moving Up	Down
3.9 and less	25	7	[1]20	
4.0 to 4.9	26	47	4	2
5.0 and above	9	6		8

[1] One sample moved up to the 5.0 and above group.

Data from a similar Forest Service study in Pennsylvania compared changes in pH on five sites after 14 years. Average change in pH for combined data from these sites was an increase of 0.4 pH units, from 3.3 to 3.7. Seven out of 101 samples had a decrease in pH. Average data, by site, are shown in Table 2.

These data are beginning to show the same tendencies as data from the other, longer term studies we have examined in this paper. In time, these sites should reach a pH equilibrium typical for forested sites in this region in the pH 4.0 to 4.9 range.

IMPLICATIONS OF NATURAL AMELIORATION OF EXTREME ACIDITY

Various concepts of soil acidity have affected public policy and economic costs for many years. Much legislation, vast amounts of labor, fuel, and equipment use, and huge sums of money have been expended in eliminating potential acid spots on lands currently being mined. Acidic areas are a high priority in allocating funds for reworking abandoned mined lands. A broader understanding of the role of natural processes and management possibilities in alleviating acidity could lead to better reclamation practices, and also influence our conception of problems associated with "acid rain."

A promising management technique is to increase levels of soil organic matter. Organic matter contributes to improved soil physical and chemical conditions. The recovery of barren acid spots may well result from inputs of organic matter from the surrounding vegetation. Possible mechanisms are increased mineral (base) cycling and microbial transformations of sulfate. Swank et al. (1984) considered that incorporation of sulfate to organic forms in forest soils could provide a buffer against the impacts of acid precipitation. Increased soil organic matter would be a possible management tool for sulfate removal from soils and for reduced acidity.

The best treatment to offset effects of sulfate input on mined lands and in precipitation may well be to increase ecosystem productivity. This approach recognizes the classic model of soil development and maintenance in which both vegetation and soil are functions of climate, parent material, topography, and biota, all as a function of time (Jenny 1980). Some organic mulches used in reclamation practices not only enhance vegetation establishment on extremely acid sites but have also been shown to increase pH (Slick and Curtis 1985). Production of organic matter by vegetation may be a new solution to perceived problems with acidity on minesoils and on soils impacted by acid precipitation.

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Table 2.--Changes in pH on five mined sites in Pennsylvania over a period of 14 years.

Item	Mosgrove	Burns	Hitchman	Schoonover	Strattanville	Total/ Average
No. Samples	35	17	15	17	17	101
1972 pH	3.2	3.7	3.3	3.3	3.1	3.3
1986 pH	3.6	4.0	3.8	3.5	3.6	3.7

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ACID SOILS RECLAMATION: APPLYING THE PRINCIPLES

J. R. Nawrot, J. Sandusky, and W. B. Klimstra

Abstract. Abandoned mine land reclamation which only focuses on the adverse impacts of current conditions often overlooks and does not appreciate the vast chemical, physical, and vegetative improvements that occur as a result of the beneficial natural processes of aging, weathering, leaching, and plant colonization. Consequently, emphasis on "instant green" cosmetic reclamation by grading/covering rather than chemical/biological reclamation by neutralization/organic matter enhancement results in unnecessary grading and exposure of previously unoxidized pyritic soils. Working with nature to improve and build existing soils, enhance vegetative succession, and treat the cause rather than the symptom, represent basic principles of cost-effective pre-law reclamation. Such principles have been instrumental in implementing successful vegetation establishment practices at Peabody Coal's 2,400-acre Will Scarlet "Old Works" area in Williamson County, IL. The value of some of these cost-effective principles was initially evaluated during research/demonstration studies at Will Scarlet over two decades ago. Implementation of these principles and practices as opposed to "further research" has contributed to extensive abatement of acid conditions resulting in a $300,000/year reduction in AMD treatment costs. This paper provides an overview of AML reclamation practices at the site of what has been called the "nation's worst" acid soils pre-law area. These include enhancing succession on acid spoils, direct vegetation of coarse refuse, and the alkaline capping and flooding of inactive slurry areas for wetland development and mine drainage treatment.

INTRODUCTION

Time and the associated benefits of weathering and aging are two basic reclamation components that money can't buy. Although the importance of aging and weathering has been recognized for decades, reclamation of acid soils in some AML projects often neglects this principle during unnecessary grading. The natural weathering and leaching of exposed soils and refuse represent an economically significant portion of geochemical reclamation that seldom is taken advantage of in design and engineering specifications.

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Unfortunately, cost-effective reclamation practices (i.e., minimal grading and enhancement of existing vegetation) are not always implemented due to other considerations such as: 1) pressure to spend all reclamation funds during one construction season or contract period, 2) the eagerness to try currently popular soil treatments or creative reclamation concepts, and 3) the misconception that more money always means better reclamation. Understandably, in some cases additional grading may be necessary to accommodate more intensive postreclamation development plans.

The gradual drifting away from basic reclamation practices of the past has ironically been a result of the abundance of State and Federal funds to research new ideas and implement new techniques. However, when researching new ideas or implementing new techniques does not include reviewing old ideas and improving old techniques, there has been and will be a shameful waste of time and money in duplicated effort. When current laboratory and small plot research projects continually conclude "further research is needed", there is little incentive for implementation of full-scale field demonstration practices. New research is perpetuated, while valuable past research is ignored.

Many past practices of acid soils reclamation have been based on simple principles:

1. **IF ITS NOT BROKE, DON'T FIX IT.**

2. **ACIDITY = LACK OF ALKALINITY.**

3. **TIME + LIMESTONE = GREEN.**

4. **TREAT THE SOURCE, NOT THE SYMPTOM.**

Implementation of these principles has resulted in the successful reclamation of thousands of acres of pre-law soils throughout the midwest and southeastern United States during the 1950's and 1970's. Rejection of past practices and these proven reclamation principles only to start over again ignores the lessons learned from successful field trials that have withstood the test of time. These old practices may only need modification or improvement for current implementation. These old principles of acid soil reclamation may never be considered trendy or sophisticated, but they bear consideration because they are simple and have been successful.

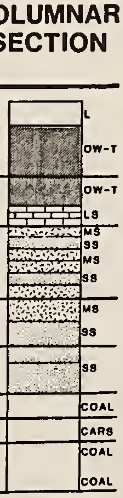
ACID SPOILS RECLAMATION

The principles of acid soil reclamation listed above have been the basis of reclamation practices at the Peabody Will Scarlet Mine pre-law "Old Works" area in Williamson County, IL. Often referred to as the "nation's worst" example of acid soils and water associated with pre-law mining, the "Old Works" area encompasses approximately 2,400 acres of acid spoils, gob and slurry, acid impoundments, and acid mine drainage. Formerly mined by Stonefort Mining Company, Peabody Coal Company assumed reclamation responsibility for the "Old Works" area when the Will Scarlet Mine was purchased in 1967.

Pre-law mining during the early 1950's and continuing into the early 1960's affected more than 2,000 acres overlying the shallow Davis and Dekoven coal seams. Extremely acid sandstones and shale characterized the roof and partings associated with the two coal seams (fig. 1). Oxidation of exposed pyritic materials in spoils and refuse areas contributed to acid runoff (table 1) exceeding 700 million gal/year.

DEKOVEN-DAVIS OVERBURDEN: STONEFORT MINING

DEPTH (FEET)	ROCK TYPE	% SULFUR	PH (1:1)	NEUTRALIZATION POTENTIAL (TONS $CaCO_3$/1,000 TONS)
0-6	LOESS	0.030	5.0	1.11
8-25	OW-TILL	0.005	7.0	2.55
25-31	OW-TILL	0.060	7.7	336.00
31-32	LIMESTONE	0.565	7.6	482.77
32-54	MUDSTONE AND SANDSTONE	0.170	7.6	12.05
54-62	MUDSTONE	0.120	7.9	40.75
	SANDSTONE	0.105	7.3	36.22
62-66	SANDSTONE	2.650	3.2	-66.29
66-72	SANDSTONE	1.090	5.1	-10.73
72-74	COAL-DEKOVEN			
74-76	CARBOLITH	12.050	2.4	-373.04
76-77	COAL-DEKOVEN			
60-63	COAL-DAVIS			



OW- GLACIAL OUTWASH

PREPARED BY CWRL-SIU-C

Figure 1. Palzo generalized overburden sequence (Smith et al. 1976).

Table 1.—Peabody Will Scarlet Old Works plant influent water quality.[1]

Parameter	Range
pH	2.4 - 3.1
Acidity[2], boiling point to pH 8.3	1,700 - 9,200
Acidity[2], cold with H_2O_2 to pH 7.3	1,500 - 8,500
Alkalinity[2], to pH 4.5	0 - 93
Specific conductivity[3]	2,800 - 7,900
Iron, total (ppm)	145 - 1,130
Iron, ferrous (ppm)	0 - 65
Iron, ferric (ppm)	145 - 1,070
Sulfate (ppm)	2,200 - 6,600

[1] From: McDonald and Grandt 1981.
[2] ppm as $CaCO_3$.
[3] μmhos/cm at 25°C.

To abate acid discharges, a mine drainage water treatment plant was designed and constructed in 1970. Capable of treating 3.5 million gal of acid water with an average acidity of 4,500 ppm each day, plant operation costs have averaged $400,000 annually from 1971 through 1984. However, without concurrent reclamation within the acid watershed, it was recognized that the plant would be needed to perpetually treat the symptoms of acid spoils runoff.

In the late 1970's under the supervision of Jim Sandusky, a reclamation program was initiated to address the acid sources rather than perpetually treat the symptoms. Previous research at Will Scarlet had identified the beneficial aspects of natural leaching in reducing acidity and salinity of weathered spoilbanks (McGrath 1972). Therefore, under this program, acid spoils were selectively graded to cover acute acid shale profiles and ensure minimal disturbance to weathered and leached materials while preserving existing vegetative cover (Nawrot et al. 1982a).

Selective grading, minimal grading, neutralization amendment, and vegetation enhancement and preservation are the major components of the Peabody "Old Works" acid spoils reclamation program. This reclamation approach emphasizes amelioration of limiting chemical factors and working with and enhancing the natural succession of vegetation on pre-law spoil areas (Lindsay and Nawrot 1981). Pre-law problem spoil areas can represent varying degrees of acidity/toxicity problems and often support a wide range of vegetative successional stages (table 2). Consequently, pre-reclamation site characterization is necessary to identify and map distinct reclamation units (table 3).

Designation of reclamation units can minimize unnecessary grading. Adhering to the first principle of acid soils reclamation - "It it's not broke, don't fix it" only those areas most in need of reclamation are treated. While Class I and II spoil areas may require aggressive reclamation efforts (e.g., grading, selective soil covering, and subsurface neutralization amendment), extensively aged and leached Class III and IV spoils may only require supplemental surface neutralization amendment and vegetation enhancement. Simplifying reclamation by grouping spoil classes I–IV may appear to be more efficient; however, the exposure of previously unoxidized acid spoil during unnecessary grading of weathered spoils (e.g., Class III and IV) can produce more extensive areas of acute acid production than existed before reclamation. Covering acid spoils or reclaiming acid impoundments with fill material from vegetated pre-law spoils does not necessarily eliminate an acid problem if soil profiles within the borrow area contain previously unexposed acid shale. Unless soil/spoil profiles of potential borrow areas are documented with soil core data or there is qualified field supervision during construction, identification of borrow areas should not be based simply on the criteria that they are nearby and well vegetated.

These back-to-basics lessons of acid spoils reclamation have been demonstrated at the Peabody "Old Works" area since the mid-1960's. Current and future reclamation continues to rely on these basic principles. Spoilbank reclamation has emphasized limestone amendment (20–40 tons/acre) of previously graded spoils (e.g., Class IIIIV), followed by cover crop establishment and/or domestic sewage sludge application for organic matter enhancement. Vegetative cover in amended spoils areas has included permanent seeding of warm season grasses (switchgrass (Panicum virgatum)) and supplemental tree planting. While supplemental tree planting has been desirable for enhancement of woody cover establishment, natural colonization by species in undisturbed spoils has successfully "reclaimed" adjacent areas.

Final reclamation of remaining "Old Works" spoil areas will occur during the next two years as more than 200 acres of marginal (Class I–III) spoil areas receive surface (0–9 inches) and subsurface (deep ripping @ 20–24 inches) limestone amendment. Amendment rates ($\geq$50 tons $CaCO_3$ eq/1,000 tons) will exceed traditional limestone requirements (i.e., immediate + reserve + potential acidity) to enhance alkaline infiltration in subsurface spoil profiles. Dry sewage sludge will also be

Table 2.--Spoilbank classification for surface mine problem sites.[1]

	Spoil Class				
	I	II	III	IV	V
VEGETATION					
Ground Cover %	0-5	10-20	20-30	30-40	40+
Successional Trend	mostly barren, advancement unlikely	scattered "islands" of herbaceous and woody cover, slow advancement	poor cover, but vegetation colonization expanding from "islands"	moderate cover with rapid colonization of bare areas	generally well developed herbaceous and woody cover
Years to Recover (natural colonization)	70+	50-70	10-20	5-10	0-5
SOIL LIMITATIONS					
pH	<3.5	3.5-4.0	4.0-5.0	5.0-6.0	≥6.0
Phytotoxicity	extensive potential acidity	high reserve acidity, extensive areas of phytotoxicity	moderately weathered, many "hotspots" remain	well weathered, only localized "hotspots" remain	accelerated organic matter accumulation and soils development
Nutrient Status	unavailable and deficient N, P, K, little or no organic matter	unavailable and deficient N, P, K contributing to poor growth and survival	low-medium nutrient availability, localized deficiencies common	localized deficiency	adequate macronutrients for sustained vegetative growth
RECLAMATION ALTERNATIVES					
Site Preparation	grading may be utilized with caution, soil substitutes may be necessary	grading may expose previously unweathered acid soils, amendments may be sufficient	grading discouraged, destruction of vegetation and exposure of acid subsoil likely, spot amendments as needed	do not grade	do not grade
Amendments	Limestone=50+ tons/ac NPK=80-100 lb/ac	Limestone=30-50 tons/ac NPK=50-80 lb/ac	Limestone=20-30 tons/ac spot application of NPK 20-50 lb/ac	limited amendments needed for enhancement and "spot" treatment	no amendments necessary unless for enhancement of existing cover

[1] Modified from Nawrot and Kolar 1982.

Table 3.— Spoil classification and associated pre-reclamation chemical characteristics[1] of the Stonefort Mining Company Pit 6 (Palzo Tract) pre-law graded spoil area[2] in Williamson County, IL. Samples collected March 1982.

Variable	Spoil Class					
	I	II	III	III/IV	IV	V
	n=31	n=20	n=6	n=9	n=8	n=6
Potential Acidity (meq H^+/100g)	16 (3-50)[3]	14 (2-78)	9 (5-14)	8 (3-13)	9 (4-15)	8 (5-11)
Soil pH	2.7 (2.3-3.1)	2.8 (2.2-4.1)	3.6 (3.0-4.3)	4.1 (3.3-4.7)	4.1 (3.5-5.0)	4.9 (3.8-6.0)
Buffer pH	6.3 (6.0-6.6)	6.3 (5.8-6.7)	6.3 (6.4-6.5)	6.5 (6.4-6.6)	6.5 (6.3-6.7)	6.6 (6.4-6.7)
Conductivity (mmhos/cm)	2.2 (0.4-7.0)	2.2 (0.4-7.0)	0.7[4] (0.3-1.6)	0.5 (0.3-0.9)	0.5 (0.3-1.3)	0.3 (0.3-0.4)
Aluminum (ppm)	192 (79-393)	183 (56-291)	200 (91-387)	217 (72-391)	171 (50-407)	127 (2-313)
	n=10	n=8	n=4	n=4	n=5	n=1
Phosphorus (ppm)						
P_1 (weak Bray)	24 (12-44)	23 (14-38)	5 (3-8)	51 (7-97)	6 (4-10)	9
P_2 ($NaHCO_3$-P)	45 (19-72)	50 (29-101)	10 (5-14)	73 (13-144)	18 (14-23)	15
Potassium (ppm)	28 (11-58)	37 (16-108)	32 (18-52)	53 (26-84)	57 (41-79)	83
Magnesium (ppm)	49 (15-140)	59 (35-95)	58 (20-80)	81 (20-110)	109 (25-310)	170
Calcium (ppm)	540 (100-1,500)	588 (200-1,000)	300 (200-500)	453 (200-750)	510 (200-1,000)	600
Sodium (ppm)	29 (23-34)	25 (20-28)	26 (25-28)	29 (27-30)	26 (23-28)	30
Hydrogen (meq H^+/100g)	8 (6-12)	8 (5-12)	5.9 (4.6-7.0)	5.2 (3.7-6.6)	5.4 (4.0-7.2)	2.1
Cation Exchange Capacity (meq/100g)	11.0 (6.8-20.9)	11.4 (6.7-16.6)	8.1 (7.0-8.7)	8.4 (5.4-11.4)	9.1 (5.4-13.4)	6.9
Percent Base Saturation						
Potassium (%)	0.7 (0.3-1.9)	0.9 (0.3-2.5)	1.1 (0.6-1.6)	1.6 (1.2-2.3)	1.6 (1.3-1.9)	3.1
Magnesium (%)	3 (1.0-6.0)	4.6 (2.5-7.5)	6.1 (2.0-9.5)	7.8 (3.1-12.4)	8.5 (3.9-19.3)	10.5
Calcium (%)	21.1 (7.4-46.2)	24.8 (9.3-40.2)	18.8 (11.5-30.1)	26.6 (18.5-33.8)	26.5 (15.5-74.2)	43.5
Hydrogen (%)	73.6 (47.9-88.2)	68.4 (53.6-84.1)	72.7 (60.2-84.3)	62.1 (50.0-74.1)	52.0 (4.1-74.2)	30.4
Sodium (%)	1.3 (0.6-9.1)	1.0 (0.5-1.5)	1.4 (1.3-1.6)	1.6 (1.0-2.3)	1.3 (0.9-2.0)	1.9

[1] From Nawrot 1983.

[2] Mined early 1960's, graded 1971-1979.

[3] Mean (min.-max.)

[4] n=5.

applied to neutralized sandstone/shale spoils to increase soil moisture and organic matter. Limestone amendments and sewage sludge are being provided through an Illinois Abandoned Mined Lands Reclamation grant.

Productive forests or pasturelands in the "Old Works" area were never considered realistic reclamation goals. However, alkaline enhancement and vegetative stabilization of ungraded and graded spoilbanks, and the generation of alkaline rather than acid runoff now represent reclamation results that were considered only remotely possible more than 20 years ago.

REFUSE RECLAMATION

Current state regulations require a 4-ft soil cover for reclamation of recently inactivated coal processing wastes (gob and slurry). However, covering may not always be the most cost-effective solution for post-law and/or pre-law refuse. Although non-toxic cover materials provide rooting media for permanent vegetation, acid-base imbalance of the refuse materials and contamination of cover materials by upward acid diffusion may occur (Sukthumrong 1975). Consequently, prior to proceeding with "cosmetic" (i.e., soil cover) reclamation, consideration should be given to implementing a "chemical" reclamation approach that addresses restoration of a favorable acid-base equilibrium. "Treat and/or cover" alternatives including neutralization amendments can minimize or eliminate acidification of soil cover as well as enhance alkalinity of the refuse acid-base system in the upper zone (0-30 inches) of active oxidation (Warburton et al. 1987).

The feasibility of reclaiming pre-law refuse without soil cover is dependent upon unique geochemical characteristics associated with variations in seams and regional geology, as well as physical factors resulting from aging and weathering (Nawrot et al. 1982b). Similar to the previous discussion of spoil aging (McGrath 1972), amelioration of acute toxic conditions resulting from oxidation and weathering is also beneficial to reclamation of pre-law acid refuse. Natural colonization of old refuse sites by native vegetation (D'Antuono 1979) has illustrated that with time mine wastes can be transformed into mine soils.

Treating and/or reclaiming mine wastes without soil offers both environmental and obvious economic benefits. Obtaining adequate soil cover can be expensive as well as detrimental to adjacent borrow areas. For most pre-law sites, adequate borrow areas were not planned for, making soil covering both impractical and expensive. Although covering can initially hide acidgenerating sources, vegetation established on thin soil veneers is often prone to drought stress and eventual erosion. Inadequate binding of soil caps due to shallow rooting inhibited by acid refuse substrates promotes sloughing and erosion of soilcovered slopes. Acid sites reclaimed with thin veneers of soil cover are extremely vulnerable to intensive post-reclamation uses. Overgrazing, neglect, lack of erosion control measures (terraces, rockdrains, etc.), or inadequate maintenance can contribute to site deterioration of AML projects.

Directly establishing vegetation on acid refuse without soil cover may not be appropriate for all sites due to topographic or hydrologic constraints. However, when feasible, building and developing refuse as a soil through alkaline and organic matter enhancement (limestone amendment and cover crop/green manuring) represents a practical approach to obtaining long-term chemical and vegetative stability of the reclaimed area. Enhancing and developing the refuse as a soil rather than reclaiming a soil cover placed over the refuse ensures that root establishment and plant cover will eventually bind and build the soil properties of the refuse substrate.

Direct vegetation establishment is best suited to those sites which have undergone an initial period of pyrite oxidation and weathering. When refuse is first deposited, little or no oxidation has occurred; consequently, immediate acidity is negligible and most materials are near neutral. Although variability occurs due to geologic and climatic factors (primarily temperature and rainfall), weathering and oxidation of fresh refuse results (after 12-18 months) in an initial acute acidification phase that is characterized by extreme concentrations of acid generation byproducts. Time required for initial acidification is variable, but may be shorter if adjacent areas contribute both acid runoff and sulfur-oxidizing bacteria to stimulate and accelerate acidification. Delays in acidification can be expected in refuse materials containing naturally occurring calcitic components; however, acid generation generally overcomes the neutralization potential due to the limited solubility of calcium carbonate. Other factors, such as particle size of refuse components, as well as weathering rates of parent material will also influence the onset and intensity of initial acidification.

Potential acidity gradually decreases (e.g., >80% reduction after 15 years in coarse refuse and only 3 years in unsaturated slurry) as fine-grained pyrite is depleted in the oxidized zone. However, chronic acid generation results from oxidation of remaining less reactive pyrite as well as the exposure of unreacted pyrite through erosion. If not disturbed by erosion or grading, a chemically stable weathered surface zone (0-36 inches) will gradually develop. Oxidized surface zones are characterized by "treatable" levels of potential acidity (e.g., 10-45 tons $CaCO_3$ eq/1,000 tons), while the underlying unoxidized zone (>100-200 tons $CaCO_3$ eq/1,000 tons potential acidity) remains relatively unreactive if not disturbed. Consequently, direct vegetation establishment is best suited to those sites that have been "abandoned" or have remained inactive and undisturbed for 5 to 10 years. Obviously, it is important that AML projects eliminate or minimize grading of weathered zones to prevent reexposure of unoxidized pyritic materials.

Gob Pile - Alkaline Enhancement and Direct Vegetation Establishment

To evaluate direct vegetation establishment (with limestone) as a cost-effective alternative for pre-law disposal sites a reclamation demonstration was initiated in 1971 by the Illinois Department of Mines and Minerals (Medvick and Grandt 1976) in cooperation with Peabody Coal Company at the Will Scarlet Mine. Reclamation of a 50-acre coarse refuse pile at the Peabody Coal "Old Works" area has emphasized the general principle of refuse aging and weathering. More specifically, reclamation was based on the previously identified principles: **Acidity = Lack of Alkalinity, and Time + Limestone = Green.**

When inactivated in 1971, surface refuse was extremely acid (pH 2.3, pyritic sulfur 4.4%) requiring approximately 130 tons/acre agricultural limestone to balance potential acidity requirements. Directly vegetated limestone-amended treatment plots were established by the Illinois Department of Mines and Minerals (Medvick and Grandt 1976) in the spring of 1971 followed in 1973 by a 0.5-acre demonstration plot. Refuse collected in 1977 from the amended and adjacent unamended portions of the experimental plot indicated limestone was effective in neutralizing surface acidity up to 3½ years after initial treatment.

To reduce chronic acid runoff in the "Old-Works" watershed, direct liming and seeding of the remaining surface area of the 50-acre gob pile was evaluated. Samples collected in March 1984 (table 4). reflected the physical and chemical effects of more than 12 years of aging and weathering. Continued oxidation and leaching had reduced potential acidity from >200 tons $CaCO_3$ eq/1,000 tons to <8 tons $CaCO_3$ eq/1,000 tons in the weathered refuse surface. Incremental sampling at 6-inch intervals indicated the zone of weathering had extended to a depth of 18 to 24 inches. Beyond the depth (30-36 inches) of physical weathering from freezing and thawing, oxidation of pyrite had been minimal.

A direct vegetation establishment reclamation plan was initiated in fall 1984 that emphasized minimum surface disturbance and maximum alkaline enhancement of the weathered surface zone. The "excess alkaline enhancement" plan included limestone amendment for immediate and reserve acidity and sufficient amendment for future oxidation as indicated by potential acidity values of previously unoxidized subsurface refuse. Surface broadcast application as well as subsurface incorporation (24-30 inch deep furrows @ 3-5 inches wide and 8-10 ft apart) were designed to provide an extension of the amended (neutralized) zone through alkaline infiltration into the unweathered coarse refuse.

Surface agricultural limestone amendment (@ 35-40 tons/acre) began in September 1984. After incorporation (disced to 9 inches), furrows were prepared using a modified cable trencher. Agricultural limestone was then applied in the trenches (@ 40-50 tons $CaCO_3$ eq/1,000 tons). Agricultural limestone was surface applied again (@ 50 tons/acre) after deep ripping. After light discing (disced to 4-6 inches), treated areas were fertilized (18-46-0 at a rate of 400 lb/acre, 0-0-60 at a rate of 250 lb/acre) and seeded with winter rye (Secale cereale) (2 bu/acre).

In the spring of 1985, reclamation continued with the establishment of 31,000 black locust (Robinia pseudoacacia) seedlings followed by supplemental tree planting in spring 1986 of 250 pin oak (Quercus palustris), 250 sweet gum (Liquidambar styraciflua), 250 smooth sumac (Rhus glabra), and 500 silky dogwood (Cornus oblique). Although soil pit excavations in fall 1986 showed predominately lateral tree root development within the limestone-amended zone, successful establishment (>60% survival) and growth of black locust are providing nitrogen and organic matter enhancement. Supplemental seeding of sweet clover (Melilotus spp.) and red clover (Trifolium pratense) is providing additional cover in association with old field annuals (e.g., Setaria spp., Rumex spp., Plantago spp., and Potamogeton spp.) established by mulching with clover seed cleaning reject.

After limestone amendment, coarse refuse samples reflected the addition of excess alkalinity and buffering capacity (>120 tons $CaCO_3$ eq/1,000 tons) in the weathered zone and establishment of nonacid (pH 6.8) conditions (table 4). Decrease of acidity below the weathered zone was initially (December 1984) evident in deep samples (≥12 inches); mean pH values 5.7 were recorded for materials that had previously been extremely acidic. Although subsequent sampling (1985, 1986, 1987) identified acidity (pH 3.2) below the zone of mechanical limestone incorporation, sufficient alkalinity remained in the weathered surface zone to maintain near neutral (pH 6.9) conditions (table 4). As current (fall 1987) neutralization potential values of amended surface refuse (158 tons $CaCO_3$ eq/1,000 tons) exceed the nearly depleted potential acidity (5.0 tons $CaCO_3$ eq/1,000 tons), persistence of non-acid conditions can be expected in the weathered surface zone. With the presence of excess neutralization potential in the amended zone, gradual dissolution of calcium carbonate and alkaline flushing to the underlying unweathered zone can further ameliorate acid conditions.

Final reclamation of the Will Scarlet gob pile will necessitate vegetation establishment on exposed slopes. Eroded steep slopes will require minimal grading prior to limestone treatment and/or soil covering. Where grading is necessary, a period of initial aging and weathering may be included to allow for chemical stabilization of freshly exposed pyritic materials.

Slurry Areas - Alkaline Capping and Organic Matter Enhancement

Similar to the 50-acre "Old Works" coarse refuse area, two large acid slurry impoundments (137 acres and 65 acres) represented extensive sources of continuous acid generation and

Table 4.—Physiochemical data for selected parameters of Peabody Will Scarlet IIA/IIB coarse refuse areas.

Sample	Paste pH	Conductivity (mmhos/cm)	Pyritic Sulfur (%)	Potential Acidity ($T\ CaCO_3$ eq/1,000 T)	Neutralization Potential ($T\ CaCO_3$ eq/1,000 T)	Phosphorus		Extractable Metals	
						P_1 Weak Bray (ppm)	P_2 Strong Bray (ppm)	K^1 (ppm)	Al^2 (ppm)
BEFORE TREATMENT									
(April/May 1984)									
0-6 in. (n=16)	2.7	3.0	0.24	7.62	-2.20	2.6	5.5	20.5	65
>12 in. (n=14)	2.2	28.0	3.98	124.50	-8.97	11.1	29.3	59.2	496
AFTER TREATMENT									
(December 1984)									
0-6 in. (n=16)	6.8	2.7	0.28	8.59	122.22	1.3	5.4	116.4	<5
>12 in. (n=14)	5.7	3.2	2.09	65.25	13.76	1.7	5.9	63.9	47
(November 1985)									
0-6 in. (n=16)	6.9	2.4	0.15	4.75	135.07	2.2	15.7	71.5	<5
>12 in. (n=14)	3.2	5.0	1.99	62.26	3.09	1.4	2.6	22.9	91
(September 1986)									
0-6 in. (n=16)	6.9	2.7	0.21	6.56	170.20	0.3	6.1	156.3	<5
>12 in. (n=14)	3.6	6.1	1.87	57.39	2.21	2.9	4.2	51.8	<206
(October 1987)									
0-6 in. (n=14)	7.0	2.4	0.16	5.00	157.60	2.8	19.6	156.5	<5
>12 in. (n=14)	2.6	16.2	2.90	91.40	2.00	5.8	12.7	87.8	396

[1] Determined from NH_4OAc extract.
[2] Determined from saturated paste extract.

runoff. The 137-acre impoundment had undergone significant weathering of oxidized surface zones (table 5). However, chronic acid runoff would require perpetual treatment by the mine drainage neutralization plant. To further reduce acid water treatment loads and associated costs, a plan was developed to utilize hydrated lime treatment plant sludge as an alkaline cap and oxygen infiltration barrier for exposed slurry areas. Residual neutralization potential (100-250 tons $CaCO_3$ eq/1,000 tons) and high alkalinity (pH 8.5) of the mine drainage treatment sludge were conducive to establishment of an alkaline substrate over acid slurry surfaces.

A 10-acre pilot study initiated in spring 1983 utilized lime sludge pumped from the treatment plant holding basin (Pit 10). After decanting and densification, the hydrated lime sludge substrate (2-10 inches deep) was fertilized, disced, and seeded with Japanese millet (Echinochloa crusgalli) to establish a moist soil cover crop.

Hydrated lime sludge capping was expanded to include slurry areas IA and IB (137 acres) and slurry areas IC3 and IC4 (65 acres). To facilitate capping, slurry embankments were raised (+5 ft) and the 137-acre impoundment was subcompartmentalized by the construction of a 900-ftlong internal embankment. Emergency spillways and water level control valves were installed to allow sequential pumping and decanting. Hydrated lime sludge was pumped directly from the water treatment plant.

After 3 years of pumping, slurry substrates have been capped by varying thicknesses (3 ft to <1 inch) of lime sludge. Periodic flushing with alkaline treatment plant discharge water has ameliorated acute acid (pH 2.8, acidity >1,200 ppm $CaCO_3$) conditions within the slurry impoundments. Although the persistence of a favorable alkalinity-acidity balance has been limited in the past by acid runoff from unreclaimed watershed soils, current reclamation efforts are addressing neutralization deficiencies of immediately adjacent spoils. Concurrent with limestone amendment of adjacent spoils and restoration of alkalinity within the slurry impoundments, liquid sewage sludge is being applied at a rate of approximately 10 dry tons/acre to enhance vegetation establishment and promote microbial sulfate reduction (Tuttle et al. 1969).

Sewage amendment accelerates recovery of the hydrated lime sludge-capped slurry impoundments while providing a more desirable substrate for establishing moist soil and wetland plants. Existing stands of reedgrass (Phragmites australis) have now expanded and are rapidly colonizing previously bare slurry areas. Plantings of other wetland species - threesquare (Scirpus americanus), hardstem bulrush (S. acutus), and river bulrush (S. fluviatilis) - have also responded favorably to amelioration of the previously acute acid conditions. Additional plantings and broadcast seeding of the moist soil annuals chufa (Cyperus esculentus), wild millet (Echinochloa spp.), smartweed (Polygonum spp.), and dock (Rumex spp.) will continue during springsummer 1988 as seasonal drawdowns of sewage sludge-capped slurry impoundments are initiated. Drawdowns of wetland/slurry substrates promotes germination of broadcast-seeded species as well as enhances the natural colonization and expansion of existing vegetation. Secondary to reclamation benefits, the reclaimed slurry impoundments and associated wetlands in the "Old Works" area provide habitat (food, cover, nesting) for a resident flock of about 100 giant Canada geese (Branta canadensis maxima) and wintering habitat for 6,000-8,000 migrating geese (B. c. interior).

SUMMARY

Reclamation of a pre-law acid area as extensive as the "Old Works" project represents a tremendous challenge as well as an outstanding opportunity to apply the basic principles of reclamation. To address extreme acid soil and water conditions required an approach that worked with nature by minimizing further disturbance in order to maximize reclamation results. While "further research" can be valuable if you can afford it, nothing has been lost by implementing techniques that have worked in the past. Acid soils require excess alkalinity; no amount of excess limestone can be considered inappropriate in a 2,400-acre watershed that has generated nothing but acid runoff for more than 25 years. No amount of organic matter can be considered too much in acid shale and sandstone spoils and refuse that would require decades to recover naturally. Any reclamation approach that eliminated or even reduced acid generation at the source can be considered successful if it minimized perpetual treatment of the symptoms.

Ironically, the extreme conditions and extensive acreage of the "Old Works" area may prove to be the most important factors in its eventual reclamation. "Too large", "too acid", and "too expensive" were factors that deterred previous attempts to initiate a comprehensive reclamation program using a traditional approach (i.e., soil covering). Consequently, a treatment plant was constructed and the source of the problem was ignored for many years. Fortunately, time and the beneficial aspects of aging and weathering contributed to amelioration of acute acid conditions through natural processes.

Reclamation problems remaining after 25 years still represent adverse conditions; however, these acid soils are now more readily "treatable" as the acid-base equilibrium has been transformed to a level where alkaline enhancement can restore and ultimately maintain favorable conditions. Reclamation units which previously exhibited extensive acid conditions, now only contain isolated zones of acid "hotspots". Continued reclamation efforts which eliminate these hotspots can complete the job that natural processes began more than 30 years ago when the pyritic overburden was first exposed. Volunteer establishment of vegetation on former refuse areas and restoration of alkaline waters in previously acid impoundments provide

Table 5.— Pre-reclamation chemical data (mean values) for surface (0-6 inch), intermediate (15-21 inch) and deep (30-36 inch) samples collected August 1983 from the Peabody Will Scarlet "Old-Works" slurry impoundment IA/IB.

Sample Location and Depth	1:1 pH	SMP pH	Conductivity (mmhos/cm)	Total Sulfur (%)	Pyritic Sulfur (%)	Potential Acidity (T $CaCO_3$ eq/1,000 T)	Immediate Acidity (T $CaCO_3$ eq/1,000 T)	Phosphate		Potassium (ppm)	Aluminum (ppm)	Iron (ppm)
								P_1 Weak Bray (ppm)	P_2 Strong Bray (ppm)			
IA												
6 in. (n=24)	2.2	3.6	21.8	3.08	0.76	23.60	-12.03	5.7	7.7	39.1	972	7,739
15-21 in. (n=8)	3.1	5.5	7.8	4.17	2.03	63.48	-2.33	8.2	15.1	16.0	274	1,404
30-36 in. (n=24)	4.9	6.4	5.9	5.37	3.00	93.73	+5.43	3.2	26.6	33.6	1,288	882
72 in. (n=5)	5.3	6.7	5.2	4.78	2.79	87.31	+9.11	2.2	17.5	30.3	242	171
Total	3.6	5.2	12.3	4.26	1.97	61.64	-2.15	4.8	16.9	33.2	945	3,590
IB												
6 in. (n=12)	2.2	2.7	23.0	2.45	0.21	6.62	-18.61	7.0	9.4	26.8	1,696	8,991
15-21 in. (n=5)	2.5	4.0	9.1	1.87	0.38	11.75	-8.74	10.2	14.9	13.1	518	1,958
30-36 in. (n=12)	3.0	4.6	7.7	2.94	1.30	40.55	-6.41	6.0	21.3	19.2	2,489	1,072
72 in. (n=2)	3.5	5.1	56	2.53	1.37	42.66	-3.41	1.5	29.1	49.6	179	120
Total	2.6	3.8	13.7	2.55	0.73	22.90	-11.32	6.8	16.2	23.1	1,715	4,219

encouragement and further incentive to complete a reclamation effort that was once considered unrealistic.

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THE VOLUNTEER COMPONENT IN REFORESTATION OF MINED LANDS[1]

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Abstract.--Volunteer trees were inventoried in three, 30-year-old stripmine plantations, each located on a distinctly different type of minesoil and each containing subplots planted with white pine (Pinus strobus), black locust (Robinia pseudoacacia), white ash (Fraxinus americana), and yellow-poplar (Liriodendron tulipifera) after mining. Volunteer trees were those that seeded-in later. Near-neutral minesoil derived from glacial till and sandstone had the greatest number of volunteers/acre at 929 trees, followed by 698 trees/acre on acidic shaly sand minesoil, and 516 trees on calcareous limestone and clay minesoil. Mean basal area/acre of volunteer trees was 13 ft^2 on the calcareous clay minesoil as compared to 26 ft^2 on each of the other two plantations. The six most numerous volunteer species were: black cherry (Prunus serotina) (31.3% of total volunteer trees), black locust (19.3%), white ash (12.4%), hawthorn (Crataegus sp.) (12.1%), red maple (Acer rubrum) (8.2%), and elm (Ulmus sp.) (7.1%). The number of volunteer trees varied with the species planted on plantation subplots, but relationships often differed among individual volunteer species in these plantations. As examples, subplots planted with black locust contained high numbers of black cherry volunteers on near-neutral and acid minesoils. Subplots planted with white pine had the fewest volunteers, except on calcareous clay minesoil where a significantly large number of white ash volunteers were found. Volunteer trees outnumbered planted trees at a 7:4 ratio, all plantations combined, but planted trees accounted for 72 percent of the total basal area and dominated the subplot stands. The importance of the volunteer component in these stands is expected to increase, although the species composition of future stands is unclear.

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INTRODUCTION

Nearly all land stripmined for coal in the Appalachian Region is eventually invaded by volunteer tree species unless cropped, grazed, or otherwise managed in a way that prevents the establishment of tree seedlings. Even when mined areas are planted with trees, regardless of species, volunteer trees appear sooner or later.

Many species of trees are known to invade plantations on mined lands. After a time, invader or volunteer trees often become numerous and, in some cases, outnumber planted trees (Ashby et al. 1980, Davidson 1981). The volunteer component may consist of species with little economic importance such as hawthorn or sassafras (Sassafras albidum), or it may contain valuable species such as ash, maple, black cherry, and oak (Quercus sp.) (Haynes and Klimstra 1975, Stiver 1949, Vogel 1977).

This paper examines the results of a study of volunteer trees on 30-year-old minesoils planted with four different tree species following mining. Results reported here are partly based on data published earlier in bulletin form (Larson 1984). Also, some ecological factors that appear to govern the establishment and growth of volunteer species on mined areas are discussed.

DESCRIPTION OF RESEARCH

Plantations and Field Work

Three 30-year-old plantations, each located on a different minesoil type in East-Central Ohio, were used in this study. The location, number of subplots inventoried, and minesoil description of each plantation are given in table 1. The greatest distance between any two plantations is less than 50 miles. These plantations were established by the Central States Forest Experiment Station in cooperation with the Ohio Reclamation Association, Ohio Division of Forestry, and several coal companies.

Each plantation consisted of several subplots which were either 70 ft x 70 ft (0.11 acre) or 105 ft x 105 ft (0.25 acre). Each subplot was planted to a single tree species. Only subplots originally planted to either white pine, yellow-poplar, white ash, or black locust and which had 160 or more surviving trees at 30 years were selected for study. This insured that moderate amounts of planted trees were present on subplots selected for study of volunteer species.

The number and diameter of all volunteer and planted trees by species were measured on a 41.7 ft x 41.7 ft (0.04-acre) sample plot located in the center of each plantation subplot. Natural reproduction of planted species was included in the volunteer inventory, except for black locust reproduction found inside subplots planted with black locust (see Results and Discussion section).

Statistical Analysis

The relationship between plantation location (main differences being minesoil type) and planted tree species to number and basal area of volunteer species on sample plots was analyzed by the method of least-squares for unequal subclasses (Harvey 1960). This type of analysis permitted calculation of residual correlations between dependent variables after treatment effects were removed.

A second statistical analysis of volunteer data was also carried out in which the density of planted trees, which varied from sample plot to sample plot, was included as a covariate. This procedure, in effect, allowed evaluation of plantation location and planted species effects without bias due to differences in density of planted trees on sample plots.

However, comparison of the first analysis without covariates to the second analysis with covariates revealed few differences, as indicated by similar probability levels of the F-tests. Unless otherwise stated, the results that follow are based on the analysis without covariates.

RESULTS

The number of volunteer trees varied greatly between the three plantations (table 2). Plantation 2 (near-neutral minesoil) had the most volunteers at 929 trees/acre, which was 44 percent greater than the number found in Plantation 1 (calcareous minesoil) and 25 percent greater than that of Plantation 3 (acid minesoil).

Within each plantation, the total number of volunteers (all species combined) varied with the particular species planted on subplots after mining (table 2). Plantations 2 and 3, with near-neutral and acid soils, were similar in that greatest numbers of volunteers were found on black locust subplots (1,192 and 975 trees/acre) and fewest volunteers on white pine subplots (550 and 375 trees/acre). In contrast, the white pine subplots of Plantation 1 (calcareous) had the most volunteers (855 trees/acre) and yellow-poplar subplots fewest (257 trees/acre). In many instances, however, individual volunteer species exhibited sharply different trends with respect to the planted species, and these data are presented later.

Volunteer trees outnumbered planted trees on all three plantations (table 2), with an overall mean of 715 volunteers/acre to 401 for planted trees. However, planted trees had a total mean basal area/acre of 55.7 ft^2 compared to only 21.8 ft^2 for volunteers. The planted species were the major dominant trees on all subplots, and their performance was evaluated in an earlier report (Larson and Vimmerstedt 1983).

A total of 20 volunteer species was found in the plantations. Plantation 1 (calcareous) had the fewest, 7 species, compared to 13 species on Plantation 2 (near-neutral) and 15 species on Plantation 3 (acid).

When data of the three plantations were combined, the six most numerous volunteer species were, in order: black cherry, black locust, white ash, hawthorn, red maple, and elm (table 3). These accounted for 90 percent of the total number of volunteer trees inventoried.

As a rule, each volunteer species was relatively abundant in only one of the three plantations (table 3). Furthermore, each volunteer species often exhibited a different distribu-

Table 1.--Location and minesoil description of three 30-year-old plantations selected for study of volunteer tree species.

Plantation	Nearest Town	Subplots[1/]	Minesoil pH	Minesoil Description
1	Georgetown	14	7.0 (calcareous)	Coarse limestone and clay
2	Alliance	14	6.5 to 7.8 (near neutral)	Glacial till,silty shale loam to sandy loam
3	Dundee	20	3.8 to 5.5 (acid)	shaly sand and stony sand

[1/] Number of subplots inventoried for planted and volunteer trees.

Table 2.--Mean number and basal area of both volunteer trees and planted trees found on sample plots located in planted subplots of Plantations 1, 2 and 3.

Plantation and Species Planted	Volunteer Trees[1/][2/] Number	Volunteer Trees[1/][2/] Basal Area	Planted Trees[2/] Number	Planted Trees[2/] Basal Area
	no./acre	ft^2/acre	no./acre	ft.^{2}/acre
Plantation 1 (calcareous)				
White Pine	855 abc	20.0 ab	345 bcd	52.8 bcd
Yellow-Poplar	257 d	16.0 ab	450 abcd	67.5 abc
White Ash	412 cd	7.8 b	625 a	48.0 bcd
Black Locust	538 bcd	8.5 ab	538 ab	19.3 d
(mean)	(516)	(13.1)	(490)	(46.9)
Plantation 2 (near-neutral)				
White Pine	550 bcd	23.5 ab	383 bcd	85.0 ab
Yellow-Poplar	900 abc	23.7 ab	412 bcd	48.3 bcd
White Ash	1,074 a	38.2 ab	500 abc	37.5 cd
Black Locust	1,192 a	19.0 ab	357 bcd	105.3 a
(mean)	(929)	(26.1)	(413)	(69.0)
Plantation 3 (acid)				
White Pine	375 cd	28.0 ab	260 d	86.0 ab
Yellow-Poplar	680 abcd	20.5 ab	320 cd	62.5 bcd
White Ash	768 abcd	17.8 ab	357 bcd	24.3 cd
Black Locust	975 ab	39.0 a	268 d	31.5 cd
(mean)	(700)	(26.3)	(301)	(51.1)

[1/] All species combined.

[2/] Within each column, means not followed by a common letter are significantly different at the 5-percent level, Duncan's new multiple range test.

tion pattern with respect to the planted species on subplots within each plantation. Thus, black cherry volunteers were relatively abundant in number and basal area on all plantation subplots planted with black locust, but particularly numerous (908 trees/ acre) in Plantation 2 (near neutral) (tables 3 and 4). The greatest basal area growth (30.5 ft^2) was attained by black cherry volunteers on black locust-planted subplots in Plantation 3 (acid) (table 4).

Subplots planted with white ash contained moderate to high numbers of black locust volunteers in all plantations and numerous hawthorn volunteers (383 trees/acre) in Plantation 2 (near-neutral) (table 3). Also, red maple volunteers were most numerous on the yellow-poplar and black locust subplots of Plantation 3 (acid), but absent or nearly so in the other plantations.

When subplots planted with black locust were sampled and inventoried, all living black locust trees were classed as "planted" because of the near-impossibility of identifying which trees were planted and which were of sprout or seed origin. Black locust can reproduce by root suckers and produces seed at about age 6 (Fowells 1965). Thus, the amount of black locust volunteers is probably under-reported in tables 3 and 4.

As stated earlier, number and basal area of volunteer trees varied with both plantation and species of planted trees. In general, these relationships were significant even after effects of the amount of planted trees present were statistically removed by covariate analysis. This is not to say that the density (number and basal area) of planted trees did not influence volunteers. Low, but significant, residual correlations between density of volunteer species and density of planted species suggest that the presence of volunteer trees decreased as planted trees increased.

Sample plots that contained a large number of volunteer trees did not necessarily have a proportionately large total basal area for volunteers (compare tables 3 and 4). The coefficient of determination (r^2) between number and total basal area of volunteers was only 0.132 (13.2 percent of the variation accounted for). Thus, both number and basal area measurements are important in the assessment of volunteer species on mined lands.

DISCUSSION AND CONCLUSIONS

In this study, both minesoil type and species of planted trees greatly influenced the amount and kind of volunteer trees that seeded-in on the areas. With regard to minesoil type, highest numbers of volunteers were found in Plantation 2 with near-neutral minesoil derived from glacial till and sandstone. Plantation 3 with acidic shaly sand minesoil had fewer volunteers than Plantation 2, but the total basal area of volunteer trees was nearly identical on both plantations. Plantation 1 with calcareous limestone and clay was least suitable for invasion of volunteer species. The macroclimate of the three plantations is similar and is considered favorable for growth of all volunteer species found in the study.

In a study of problem spoilbanks in Illinois, Lindsay and Nawrot (1981) noted that density of natural vegetation varied according to chemical composition of the minesoil, rather than with time since mining. Also in Illinois, Smith and Klimstra (1987) observed that only scattered growths of dewberry (Rubus flagellaris) and grasses occurred on areas with large surface accumulations of limestone rocks and boulders.

The effect of planted species on volunteers was varied. In fact, each individual volunteer species had a distinct distribution pattern with regard to both planted species and minesoil type. As examples, black cherry was particularly numerous in planted black locust stands on near-neutral and acid minesoils. Planted white pine stands contained relatively few white ash volunteers except on calcareous clay minesoils. Here, the mitigating effect of pine on the high pH soil conditions and/or the clay soil may have aided ash seedling establishment.

Somewhat similarly, Ashby et al. (1980) reported that black locust stands in Indiana, Missouri, and Kansas were favorable for invasion. In Illinois, Smith and Klimstra (1987) found only slippery elm (Ulmus rubra) and boxelder (Acer negundo) invaded and were established as part of the canopy of a shortleaf pine (Pinus echinata) plantation planted on an area mined in 1942. These authors also noted that a black locust plantation established in 1945 was dominated by volunteer slippery elm, boxelder, and black cherry in 1976-78.

In this study, the near-absence of white ash volunteers in planted white ash stands suggests an allelopathic relationship. Many of the planted white ash were producing seed at the time of inventory.

Some general observations on the availability of volunteer seed on the plantations were made. First, one can assume that most of the volunteer seed was carried into the plantations by wind or animals. Second, some volunteer white ash probably originated from seed of the planted trees, and black locust volunteers from root suckers of planted trees. Volunteers of white pine and yellow-poplar, the other two planted species, were not found. Third, the uneven distribution of volunteer species in these plantations appears to be related to differences in species composition of nearby stands. The numerous mature hawthorn trees in an old field adjacent to Plantation 2 and red maple trees near Plantation 3 were the probable seed sources for volunteers of these species in these plantations.

In our study, the number of volunteer species and their relative abundance in each plantation varied widely. Overall, black cherry was the most numerous volunteer, due in large part to its superior numbers in Plantation 2. Several other species were also relatively abundant in only one of the three plantations.

Several researchers have listed the most common volunteer tree species found on stripmined land in their areas. In an extensive study in Illinois, Ashby et al. (1978) reported the number of volunteer species in each of five mining

Table 3.--Mean number of trees of the six most abundant volunteer species found on sample plots located in planted subplots of Plantations 1, 2 and 3.

Plantation and Species Planted on Subplots	Volunteer Species[1]					
	Black Cherry	Black Locust	White Ash	Hawthorn Species	Red Maple	Elm Species
	--number/acre--					
Plantation 1 (calcareous)						
White Pine	65 d	245 ab	465 a	20 c	0 b	60 ab
Yellow-Poplar	117 d	75 b	50 b	0 c	0 b	0 b
White Ash	0 d	406 a	0 b	0 c	0 b	0 b
Black Locust	175 bcd	0 [2]	187 b	0 c	0 b	100 ab
(mean)	(89)	(181)	(176)	(5)	(0)	(40)
Plantation 2 (near neutral)						
White Pine	150 cd	29 b	25 b	167 bc	4 b	33 b
Yellow-Poplar	187 bcd	187 ab	25 b	312 ab	25 b	75 ab
White Ash	383 bc	150 ab	17 b	383 a	0 b	42 b
Black Locust	908 a	0[2]	0 b	150 bc	0 b	33 b
(mean)	(407)	(91)	(17)	(253)	(7)	(46)
Plantation 3 (acid)						
White Pine	61 d	125 ab	70 b	0 c	72 b	28 b
Yellow-Poplar	105 d	75 b	75 b	0 c	285 a	85 ab
White Ash	125 d	367 a	17 b	8 c	83 b	8 b
Black Locust	417 bc	0[2]	133 b	0 c	242 a	150 a
(mean)	(177)	(144)	(74)	(2)	(170)	(68)

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[1] Within each column, means not followed by a common letter are significantly different at the 5-percent level, Duncan's new multiple range test.

[2] Planted and volunteer black locust not differentiated (see text).

Table 4.--Mean basal area of trees of the six most abundant volunteer species found on sample plots located in planted subplots of Plantations 1,2, and 3.

Plantation and Species Planted on Subplots	Volunteer Species[1]					
	Black Cherry	Black Locust	White Ash	Hawthorn Species	Red Maple	Elm Species
	--ft^2/acre--					
Plantation 1 (calcareous)						
White Pine	0.26 c	17.73 a	0.74 a	0.07 b	0 a	0.45 a
Yellow-Poplar	0.26 c	7.93 a	0.22 a	0 b	0 a	0 a
White Ash	0 c	5.53 a	0 a	0 b	0 a	0 a
Black Locust	4.49 bc	0 [2]	0.22 a	0 b	0 a	1.88 a
(mean)	(1.25)	(7.80)	(0.30)	(0.02)	(0.00)	(0.58)
Plantation 2 (near-neutral)						
White Pine	10.50 bc	4.40 a	0.78 a	1.48 b	0.04 a	2.90 a
Yellow Poplar	15.25 b	6.01 a	0.13 a	0.50 b	0.02 a	0.68 a
White Ash	6.75 bc	22.91 a	0.02 a	8.01 a	0 a	0.20 a
Black Locust	15.51 b	0 [2]	0 a	0.87 b	0 a	0.50 a
(mean)	(12.00)	(8.33)	(0.23)	(2.72)	(0.02)	(1.07)
Plantation 3 (acid)						
White Pine	5.00 bc	17.16 a	2.18 a	0 b	1.75 a	0.30 a
Yellow-Poplar	5.49 bc	6.53 a	2.79 a	0 b	5.00 a	0.22 a
White Ash	5.23 bc	8.36 a	0.09 a	0.50 b	1.26 a	0.05 a
Black Locust	30.49 a	0 [2]	2.61 a	0 b	3.00 a	0.92 a
(mean)	(11.55)	(8.01)	(1.92)	(0.13)	(2.75)	(0.37)

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[1] Within each column, means not followed by a common letter are significantly different at the 5-percent level, Duncan's new multiple range test.

[2] Planted and volunteer black locust not differentiated (see text).

districts ranged from 13 to 28, and that each district had a different "most frequently found volunteer species." These species were elm, black cherry, cottonwood (Populus deltoides), oak, and dogwood (Cornus florida). In Ohio, a bottomland site 2 years after mining had volunteer trees of sycamore (Platanus occidentalis), sugar maple (Acer saccharum), elm, yellow-poplar, and white oak (Quercus alba) (Merz and Plass 1952). Common volunteer species on spoils in Indiana were red oak (Q. rubra), elms, green ash (Fraxinus pensylvanica), red maple, sycamore, cottonwood, sassafras, black cherry, black willow (Salix nigra), and red cedar (Juniperus virginiana) (Stiver 1949, Byrnes and Miller 1973). In western Pennsylvania, invader species were aspen (Populus deltoides), fire cherry (Prunus pennsylvanica), black cherry, and red maple (Bramble 1952).

It is apparent from the cited reports and this study that there are many potential invader species. This study concluded that their occurrence on a particular site is largely determined by the following factors: minesoil type, climate, topography, seed source, established vegetation, damaging agents, and time since mining.

Ashby et al. (1978) reported that invasion of volunteers on planted mined areas in Illinois occurred in two stages: first, early invasion by cottonwood and sycamore when areas were open; and second, later invasion by other species after planted trees or early volunteers were established. No such "two-stage" invasion of volunteers was apparent in this study, and pioneer trees of cottonwood and sycamore were nearly absent in plantations.

The early stages of forest succession in the three plantations are evident from the list of volunteer species in table 3. In the future black cherry and the somewhat more tolerant species such as maple, ash, and elm will probably proportionately increase on most areas, especially as black locust trees are overtopped. In every planted type, individual volunteer trees on favorable micro-sites outgrew nearby planted trees. Most volunteers were understory trees, however.

The expected increase in importance of the volunteer component in these planted stands is indicated by a study of still older plantations on mined areas in Pennsylvania. Davidson (1981) evaluated 19 coniferous plantations ranging from 46 to 61 years of age. Volunteer species accounted for one-third of the total volume in plantations. Black cherry outnumbered other volunteer species 2:1. Aspen and red maple were present in more than one-half of the plantations.

The nature of the climax or near-climax succession in the three plantations is unclear. Plantation 2 is in the beech forest type, and Plantations 1 and 3 are in the oak-hickory forest type. Aharrah and Hartman (1973) speculated that coal spoils of Pennsylvania will eventually be revegetated with oak-hickory forests because that is the climax vegetation of the area. In northern West Virginia, most iron ore spoils 85 to 119 years old were dominated by oak species (Tryon and Markus 1953). However, in southern Illinois, Smith and Klimstra (1987) report that vegetative composition on naturally revegetated spoils suggest succession to a flood plain forest rather than to oak-hickory typical of the region.

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VOLUNTEER REVEGETATION PROCESSES ON ACID COAL SPOILS IN NORTHWESTERN PENNSYLVANIA[1]

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Abstract.--The vegetation on 20 non-resoiled bituminous strip mines in northwestern Pennsylvania was surveyed to study the factors which account for variability in the quantity and quality of the vegetation. The sites ranged in age from 12 to 41 years. All had acid spoils, and 15 had been planted with trees before abandonment. Two revegetation patterns were discovered. One group of 10 sites had high tree densities (2,333 stem/ha average), high basal area (13.5 m^2/ha average), and were at various stages of forest development. As these sites aged, bare soil disappeared and litter increased. The second group had lower tree densities (1,186 stem/ha average), lower tree growth (2.6 m^2/ha average), and were not developing into forest communities. Instead, the spoils were characterized by patchy vegetation and had large open areas. As these sites aged, bare soil disappeared, but only lichens and mosses increased. The different revegetation patterns were not generally a result of the success or failure of tree-planting efforts. Densities of living planted trees did not differ significantly between the groups. The extent of colonization by volunteer trees, primarily aspens, was the most important determinant of high tree density and eventual forest development. Development of a forest community on the poorly vegetated sites is largely dependent on the recruitment of new trees into open areas. Except for sporadic colonization of grass clumps by red maple, very little recruitment of new trees was occurring. If methods to stimulate colonization of these areas by volunteer trees could be developed, a low-cost reclamation option might be available for thousands of poorly vegetated sites in Appalachia.

INTRODUCTION

The vegetation of non-resoiled, acidic mine spoils is often quite variable. In northern Appalachia, spoils can develop into dense woodlots within 15-25 years or remain sparsely vegetated or barren for many decades. Although several studies have described the variability of vegetation on unreclaimed, acidic spoils (Croxton 1928, Bramble and Ashley 1955, Byrnes and Miller 1973, Johnson et al. 1982; Gibson and Risser, 1982), few attempts have been made to explain the factors that underlie this variability. Without such understanding, it is unlikely that low-cost reclamation methods can be developed that emphasize natural revegetative processes instead of the expensive, complete reconstruction of sites.

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This paper describes the vegetation of 20 abandoned strip mine sites in northwestern Pennsylvania that vary in age from 12 to 41 years. All were abandoned without any resoiling efforts, and most sites were planted with trees before abandonment. Four sites were limed and fertilized before abandonment. The paper focuses on the general revegetation patterns, the importance of volunteer vegetation (as opposed to planted trees), and factors contributing to the persistence of sparsely vegetated spoils.

STUDY AREA

The study area encompassed 200 m^2 (80 mi^2) in northwestern Pennsylvania (fig. 1). Lower Allegheny Coals (Clarion, Brookville, Lower Kittanning, and Middle Kittanning coals) outcrop throughout the area and have been strip mined by many different operations since the 1930's. Overburdens in the study area are generally characterized by an excess of acid-producing over acid-neutralizing compounds (Williams, et al. 1982). Extensive strip mining in the 1950's and 1960's resulted in thousands of acres of poorly vegetated, extremely acidic spoils and the pollution of most streams in the study area with acid mine drainage. Most of the mining occurred prior to Federal environmental regulation, and State laws in effect during the period only required minimal regrading and planting efforts. All of the sites described in this report were abandoned prior to enactment of resoiling regulations in Pennsylvania in 1973.

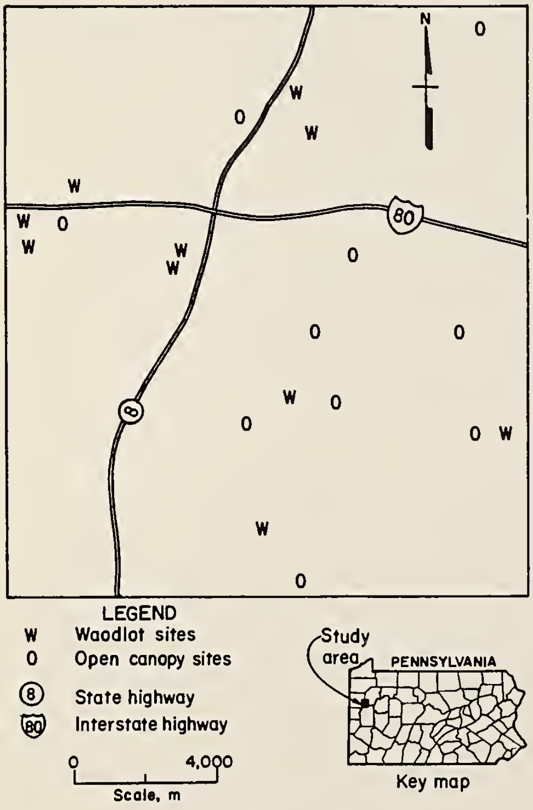

Figure 1.--Location of the study area in Pennsylvania.

METHODS

Initially, all abandoned mine sites in the study area were located, inspected for general reclamation and vegetative characteristics, and aged using Pennsylvania Department of Environmental Resources (DER) permit application records. Sites were sorted into three groups: unaged sites (no permitting records), aged sites without resoiling, and aged sites with resoiling. From a pool of 88 aged, non-resoiled sites, 26 were selected using a stratified random design that maximized the age spread. Sites varied in age from 12 to 41 years. The detailed reclamation history of these 26 sites was determined by reviewing permit files available from the DER in Harrisburg, PA.

The vegetation and soils on each site were sampled at three points. These points were randomly located in flat or gently sloping areas. Because of this topographic constraint, the results presented in this paper may not be applicable to steep spoils with slope instability problems. At each point a 0.02 ha (0.05 a) circular plot was established, and all trees within it were identified and placed into one of four DBH size classes: less than 2.5 cm, 2.5 - 15.0 cm, 15.0 - 18.0 cm, greater than 18.0 cm. Counts within the plots were used to estimate tree stem density. Dead stems were counted, but unless otherwise noted, were not included in density calculations. Basal area was estimated in the field using a basal area gauge (5 BAF). Because this method is inaccurate at low sampling densities for sites with small-diameter trees, basal areas were also estimated from the DBH categories. The correlation between these estimates and field measurements with the basal area gauge was good (r^2 = .94). Results calculated with the second method are reported here because it was considered more accurate on poorly vegetated sites.

In each plot, four 0.5 m^2 ground cover quadrats were established; one centered on the original point and three randomly located. Within each quadrat, cover elements were identified and classified using the Daubenmire cover scale: 0-5%, 5-25%, 25-50%, 50-75%, 75-95%, 95-100% (Mueller-Dombois and Ellenberg 1974). Because cover elements can overlap, this method can result in total cover estimates greater than 100%. The amount of bare soil in each quadrat was also estimated to the nearest 5%.

Soil pH samples were collected from the center of each quadrat by brushing aside any loose ground cover, digging and mixing an area of about 5 cm^2 by about 2.5 cm deep, and collecting approximately 25 cm^3 of soil which was immediately mixed with 50 mL of distilled water. The pH of this solution was measured within 2-3 hours with a Fisher field pH meter.

Upon preliminary review of the field data and permit records, six sites were determined to have been affected by secondary mining or reclamation efforts and were excluded from analytical consideration. Four sites were determined to have been limed and fertilized before abandonment. These sites were not excluded, but the additional reclamation effort was noted during interpretation of the results.

After completion of the survey, additional vegetative and soil pH sampling was done at

Table 1.--Tree stem density on woodlot and open canopy sites.

	Total		Planted[1]		Volunteer	
Site Group	den (sx)		den (sx)		den (sx)	
Open Canopy	1186 (154)	a[2]	682 (240)	a	777 (131)	a
Woodlot	2333 (142)	b	856 (252)	a	1563 (291)	b
Woodlot less two pine plantations	2380 (173)	b	554 (188)	a	1895 (237)	b

den = density in stems/ha.
sx = standard error of mean.

[1] "Planted" calculations are based on six open canopy sites and nine woodlots sites.

[2] Densities with same lower case letter in the same column are not significantly different at 0.05 level.

Table 2.--Tree basal area on woodlot and open canopy sites.

	Total		Planted		Volunteer	
Site Group	BA (sx)		BA (sx)		BA (sx)	
Open Canopy	2.63 (0.83)	a	1.45 (0.56)	a	1.69 (0.42)	a
Woodlot	13.51 (2.43)	b	5.34 (2.95)	b	8.70 (2.10)	b
Woodlot less two pine plantations	12.41 (2.03)	b	1.90 (0.65)	a	10.75 (2.02)	b

BA = basal area in m/ha.
sx = standard error of the mean.

[1] "Planted" calculations are based on six open canopy sites and nine woodlots sites.

[2] Basal areas with same lower case letter in the same column are not significantly different at 0.05 level.

Table 3.--Ground cover on woodlot and open canopy sites.

	Lichen/Moss		Vol Grass		Herbs/shrubs		Litter	
Site Group	mean (%)	age corr[1]	mean (%)	age corr	mean (%)	age corr	mean (%)	age corr
Open Canopy	38.3	+.61	25.7	ns	11.2	ns	22.9	ns
Woodlot	25.5	-.67	9.3	ns	43.3	ns	82.5	+.77

"Vol Grass" = volunteer grass.
ns = not significant.

[1] Spearman rank correlation between age and the ground cover component evaluated at the 0.05 level.

site 12. This 12-year-old mine consisted of graded, non-resoiled Middle Kittanning spoil covered by quite heterogeneous vegetation. Approximately one-third of the mine was covered with dense stands of volunteer trees. Volunteer grasses had developed a fairly dense cover (>75%) in some areas, while in others the spoils were completely bare. Numerous pH measurements were made of surface samples collected according to the type and amount of vegetative cover.

RESULTS AND DISCUSSION

Two revegetation patterns were evident on non-resoiled spoils in the study area (Hedin 1987; Hedin and Ehrenfeld, in preparation). Some spoils had high densities of trees and were covered with litter and understory herbs and shrubs where canopies had closed. Other spoils had low densities of trees, and the surfaces were either bare or covered with volunteer grasses, lichens, and mosses.

These patterns were evident on a site level (tables 1, 2, and 3). All sites older than 30 years (n=6) were closed canopy woodlots. Younger sites which had been limed and fertilized before abandonment also had high tree stem densities and were developing into woodlots. All other sites less than 30 years old were characterized by low densities of trees and large areas of sparsely vegetated spoils. Because sites with high densities of trees are on a successional path that results in a closed canopy forest in 25-35 years, they will be referred to as "woodlot" sites. The sites with lower densities of trees and large open areas are not developing directly into a woodlot and will be referred to as "open canopy" sites.

The ground cover differed significantly between woodlot and open canopy sites (table 3). The latter were dominated by lichens (primarily *Cladonia*) and mosses (primarily *Polytrichum*), the volunteer grasses broomsedge (*Andropogon virginicus*) and poverty grass (*Danthonia spicata*), litter, and bare spoils. On woodlot sites the spoils were generally covered with litter, herbs, and shrubs. For both groups total ground cover increased and bare soil decreased as site age increased. However, the manner in which the ground became covered differed between groups. On open canopy sites only lichens and mosses increased with age (see age correlations in table 3). On the oldest open canopy sites lichens and mosses often formed mats that covered more than 75 pct of the ground-cover quadrats. On the woodlot sites, lichens and mosses decreased with site age, and litter increased. All spoils older than 30 years had a complete litter ground cover.

These different revegetation processes were not generally due to the success or failure of tree planting efforts (tables 1 and 2). Trees had been planted on 9 of 10 woodlot sites and 6 of 10 open canopy sites. Planted trees dominated only two woodlot sites, both of which were dense pine plantations. The survival of planted trees on woodlot sites, judged from current density, was higher but not significantly different than that on open canopy sites. The basal area of planted trees was higher on woodlot sites, largely because of high growth on the two successful sites. When these sites were excluded from the comparison, tree growth of planted trees did not differ between the groups.

Volunteer trees were the most important delineator of the revegetation processes. The density of volunteer trees was significantly higher on woodlot sites than on open canopy sites. Most importantly, on woodlot sites volunteer trees had colonized areas where trees had either not been planted or had died. On open canopy sites, colonization of these open areas was variable and often too sparse to result in closure of the canopy except in isolated groves.

The most important volunteer trees were aspens, *Populus grandidentata* and *P. tremuloides*. On woodlot sites aspens dominated the largest size classes of volunteer trees, suggesting that they were the principal colonizers in the first decade following abandonment. On 8 of 10 open canopy sites, aspens represented more than 80% of the volunteer stem density. On these sparsely vegetated spoils, root sprouting had often resulted in small groves of aspens. However, because they remained quite windswept, the spoils beneath were often bare or covered with only lichens and mosses. Aspens were found to be growing and clonally reproducing in very acid soils. On site 12, the pH of surface soils under aspens growing on barren spoils averaged 3.8 (n=53). However, aspens did not appear capable of colonizing open, acidic spoils by seed. Very few seedlings were observed in such areas that could not be associated with a root from a nearby, adult aspen. Aspen's importance thus was due to its original ability to colonize fresh spoils, its tolerance of extremely acidic conditions, and its root sprouting growth form.

Red maple (*Acer rubrum*) was the second most common volunteer tree. It was observed in old woodlot sites and growing in completely barren spoils on several open canopy sites. On site 12, the pH of surface soils under such maples averaged 3.7 (n=6). This indicated that red maple was capable of growing in extremely acidic soils. Maples were also observed colonizing clumps of volunteer grasses on several poorly vegetated sites. The process was most evident on site 12 (table 4). Numerous red maple seedlings were observed in clumps of grass, even within otherwise barren areas. Although soil pH was significantly higher under grasses than in barren areas, this difference was not the primary facilitating factor. Little colonization occurred in bare soil within the grass-dominated areas, despite higher pH. The more important role of grass clumps was probably to trap blowing seeds and provide a moist microenvironment for germination and inital seedling development.

Table 4.--Relationship between ground cover, density of red maple seedlings, and soil pH on a 12-year-old site

Ground Cover	area sampled (m2)	Seedling Density (stems/m^2)	soil pH
Bare Soil	377.1	0.01	3.54
Clumps of Grass in Barren Areas	15.4	4.03	3.70
Grass Area: Clumps	17.0	6.47	3.93
Grass Area: Bare soil	11.3	0.17	3.85

This recruitment process was quite spoil-specific. It was important in areas where grasses were a dominant cover component and where red maple seed sources were numerous. These conditions were only satisfied at two sites: the 12- and 15-year-old sites. Poorly vegetated spoils on the other sites were usually missing one or both of these conditions, and recruitment of maples was less common and sporadic.

Black cherry (Prunus serotina) was observed in the canopies of some woodlots and also growing on open canopy sites, but like red maple, the densities were quite variable. The high densities of black cherry that were observed on two woodlot sites appeared to be associated with dead black locust plantings. In four areas where the density of dead locust stems averaged 445/ha, black cherry averaged 1,050 stems/ha, and many of these were canopy-sized. In two areas on the same sites where no dead or alive black locust were observed, black cherry only averaged 124 stems/ha. (These latter areas had aspen canopies.) A similar facilitative relationship between black locust and recruitment by black cherry has been found for Ohio spoils (Larson 1984).

LONG-TERM SUCCESSIONAL CHANGES ON OPEN CANOPY SITES

Eventually, even the open canopy sites are expected to develop into woodlots. The number of decades required for this succession is dependent on the size of open areas and the rate at which they are revegetated by clonal expansion of existing trees and colonization by new trees. Rates of expansion of aspen clones on acid spoils have never been reported, however, on alkaline iron ore spoils in Minnesota, Leisman (1955) found that quaking aspen expanded by 3.3 m/decade. This rate does not account for the additional 10-20 years required for young root sprouts to reach mature size. On sites characterized by unvegetated areas less than 10 m across and high densities of aspen, this process is capable of causing woodlot development after several decades of clonal expansion. Several open canopy sites in the study area fall into this category. However, thousands of sites in northern Appalachia contain much larger open areas and/or low densities of clonally reproducing trees. On such sites, development of a woodlot condition is primarily dependent on colonization of new trees into open areas. This process is logically related to the amelioration of conditions that currently limit colonization.

Several chemical and physical factors combine to limit growth on bare acidic spoils. The pH of completely bare soils in the study area was typically less than 4.0 and on site 12 was 3.54 (n=94). This pH level is toxic to most plants (Arnon and Johnson 1942, Coleman and Thomas 1967) and few seeds germinate under such acid conditions. Extremely acidic spoils also typically have high exchangeable aluminum levels which cause shallow and irregular root development (Berg and Vogel 1973). Seedlings with root deformations are quite vulnerable to extremes in soil moisture and temperature that are common on unshaded spoils (Deely and Borden 1973, Bell and Ungar 1982). Although these conditions are too harsh for colonization and establishment by most seeds, they are suitable for growth by many plants with established root systems (Bell and Ungar 1982).

Over time, the extreme chemistry of bare spoils ameliorates, and they are invaded by vegetation. In the study area, both soil pH and exchangeable aluminum were strongly related to spoil age (Hedin 1987). The most important invaders of bare acid spoils in northern Appalachia are grasses, lichens, and mosses (Bramble and Ashley 1955, Bell and Ungar 1982, Huey 1973). Because these plants cover or shade the spoils and provide important inputs of soil organic matter, one might expect that colonization by trees would soon follow. In the study area, only grasses show such facilitative tendencies, and the effect is quite spoil-specific. Only those open areas with both coverage of grass and large numbers of nearby seed sources were observed to have high recruitment of volunteer trees.

The most common cover of open areas in the study area was by lichens and mosses. On the oldest sites, extensive mats were common. Although no temperature or moisture measurements were made, it is reasonable to expect significant moderation of soil temperature and moisture extremes in these areas. Soils under these mats were also less acidic than in bare areas. The average pH of soils in quadrats with lichen and moss covers greater than 50% was 4.37 (n=41) compared to an average pH of 3.80 for quadrats with greater than 50% bare soil. Numerous tree seedlings were observed on woodlot soils with similar pH, but very few tree seedlings were observed in areas dominated by lichen and mosses. The cause of this low colonization may be biochemical. Chemicals produced by the dominant lichen, Cladonia, have been shown to reduce tree seed germination (Brown, 1967) and also to inhibit growth of mycorrhizae fungi that are important symbionts of successful woody colonizers on acid spoils (Goldner et al. 1986).

It thus seems that, although established trees are quite capable of growing on bare acidic spoils, initial establishment is quite difficult. Depending on the ground cover that invades the spoils in the first three decades of abandonment, this colonization problem may disappear or persist. When open areas are small and aspens are abundant, clonal expansion can fill in voids and result in development of a woodlot in 40-75 years. When open areas are larger, but become vegetated with grasses that facilitate secondary colonization by maples, woodlot development in a similar timeframe appears possible. However, where open areas are large and a cover dominated by lichens and mosses develops, minimal recruitment of new trees occurs in the first 30 years of abandonment. How long the colonization deterrence will persist is unknown, but it seems assured that the patchy, sparse vegetative conditions will persist, at the minimum, for 50-100 years after original abandonment.

RECLAMATION POSSIBILITIES

The revegetation options for these sites and similar ones throughout Appalachia range from complete reconstruction to complete neglect. Those sites with dangerous highwalls or pits require regrading efforts which will necessarily destroy the current soils and vegetative communities. However, thousands of spoils do not have features that require regrading work and are thus amenable to alternative, less costly revegetation strategies. In areas where woodlots are consistent with surrounding land uses and have aesthetic, forestry, or wildlife value, revegetation to a forested condition should be considered. One method of attaining this condition that has not been considered is the stimulation and acceleration of natural reforestation processes.

This strategy requires that the factors preventing colonization of sparsely vegetated spoils be identified, and methods be developed that would remove the limitations for several growing seasons. In northern Appalachia such research efforts should focus on aspen trees because they are capable of densely colonizing spoils, they grow quickly (Perala and Carpenter 1985), they can fill in small uncolonized areas by root sprouting, they facilitate the colonization of more valuable tree species, and their seeds are readily available every spring.

Indirect evidence exists that liming and fertilization can stimulate colonization of aspen trees on acidic spoils. One of the sites originally included in this survey was eliminated from analytical consideration because the current landowner had limed and seeded portions of the spoils with grasses and legumes 10 years ago. The spoils have reacidified and most of the grasses and legumes have since disappeared, however, the spoils are now densely covered with young aspen saplings, most of which are not root sprouts. A similar cohort of young aspens was not observed on unamended portions of the site (Hedin 1987). During the construction of Moraine State Park in western Pennsylvania, acid spoils were limed and planted with a variety of tree seedlings. Most of the planted trees died (Medve 1973); however, the spoils were densely colonized by volunteer trees, primarily aspens (Medve 1974). If a method for determining the proper mixture of limestone and fertilizer necessary to stimulate colonization of poorly vegetated sites could be developed, local groups would have a low-cost reclamation option that would dramatically change the vegetation and landscapes of many extensively strip mined areas.

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TRIGGER FACTORS INITIATING NATURAL REVEGETATION PROCESSES ON BARREN, ACID, METAL-TOXIC SOILS NEAR SUDBURY, ONTARIO SMELTERS[1]

Keith Winterhalder[2]

Abstract.--A century of sulphur-dioxide fumigation, copper and nickel particulate deposition, fire, soil erosion, and enhanced frost action has created 10,000 ha of barren land and 36,000 ha of stunted, open birch-maple woodland in the Sudbury area. Following environmental improvement, several species including tufted hairgrass (Deschampsia caespitosa (L.) Beauv.), tickle grass (Agrostis scabra Willd.), redtop (A. gigantea Roth), and dwarf birch (Betula pumila L. var. glandulifera Regel) have colonized barren sites, but extensive areas remain barren. Manual surface application of limestone, with or without an accompanying grass-seed/legume-seed/fertilizer application, leads to immediate colonization by woody species, including white birch (Betula papyrifera Marsh.), trembling aspen (Populus tremuloides Michx.), and willows (Salix spp.), with stunted relict individuals on the barren land providing the seed source. Nevertheless, red maple (Acer rubrum L.), a prominent relic, is unable to regenerate from seed on untreated or limestone-treated land. Since conifers have not so far colonized spontaneously, red pine (Pinus resinosa Ait.), jack pine (P. banksiana Lamb.), white pine (P. strobus L.), and white spruce (Picea glauca (Moench) Voss) - normal components of the climax vegetation of the region - have been planted in simulated natural groupings to improve species diversity and to provide a seed source for future colonization.

INTRODUCTION

For approximately 100 years, the Sudbury landscape has been ravaged by logging, fire, soil erosion, enhanced frost action, sulphur dioxide fumigation, and copper, nickel and iron particulate fallout from the region's three smelters (Winterhalder 1984). This complex of interacting factors has given rise to zones of barren land around the three smelters totalling 10,000 ha. Predominantly a mosaic of stony slopes interspersed with rock outcrops and fine sand or silty valley bottom soils, the barrens also include occasional gully-eroded clay at the margins of the valleys as well as expanses of barren peat that were originally bogs and cedar swamps. Surrounding the barrens is a 36,000 ha zone of stunted, semibarren woodland, characterized by patches of bare soil between the relict, coppiced trees (Watson & Richardson 1972; Amiro & Courtin 1981). Following smelter closures and cutbacks as well as the construction of a 381-m smokestack in 1972, it was expected that vegetation would gradually return to the barrens. Recolonization was confined, however, to relatively favourable sites and to specific species, some of which have been shown to have evolved a metal tolerance (Cox & Hutchinson 1980). Soils in the Sudbury region were shown (Winterhalder 1975) to display a pattern of decreasing pH and increasing copper and nickel content as the three smelters are approached, the vegetation pattern conforming with the soil zones. Table 1 shows mean soil chemical parameters (as measured in 1969) in relation to fumigation zones established by the Ontario Department of Energy & Resources (Dreisinger & McGovern 1971).

Since the closure of one of the three smelters, at Coniston, in 1972, there has been a distinct rise in mean soil pH in that area. By 1975, the mean pH of Coniston soils had risen from the 3.0 - 3.5 range measured in 1969 to a 4.0 - 4.5 range (Winterhalder 1976).

Early revegetation research showed that limestone application is an essential prerequisite to revegetation

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Table 1.-- Soil chemical parameters in relation to fumigation history (n = 10).

Fumigation zone	Mean pH ± s.d.	Mean total copper mg/kg±s.d.	Mean total nickel mg/kg±s.d.
None	5.0 ± 0.2	100 ± 20	200 ± 30
Perceptible	5.0 ± 0.2	200 ± 30	420 ± 120
Light	4.7 ± 0.1	320 ± 80	400 ± 120
Moderate	4.3 ± 0.1	900 ± 300	750 ± 300
Heavy	3.8 ± 0.3	1,250 ± 500	1,930 ± 900

(Winterhalder 1974). At first, revegetation was confined to flat, sandy sites accessible to agricultural machinery, where shallow cultivation of the soil surface was carried out (Winterhalder 1975) in the belief that it was necessary to bring less metal-contaminated soil to the surface. Later it was shown that not only was it possible to establish a grass-legume mixture on barren, stony slopes by manual surface application of limestone, fertilizer, and seeds (Winterhalder 1983a), but that limestone application in itself was an effective trigger-factor in initiating "natural revegetation" (i.e., spontaneous colonization) by a wide variety of species (Winterhalder 1983b).

COLONIZATION OF BARREN LAND WITHOUT TREATMENT

In the late 1960's, the only plants found in "barren" sites were relict woody plants that had survived the complex of environmental factors responsible for the loss of the original vegetation. Trees falling into this category were mostly white birch, red maple, and red oak (Quercus borealis Michx.f.) in drier sites and trembling aspen in moister areas. While the three former species took on a coppiced form, with suckers arising from the base of a stool, the aspens existed as clonal patches arising from root suckers. Relict woody shrubs included the common blueberry (Vaccinium angustifolium Ait.) and larger shrubs such as wild currant (Viburnum cassinoides L.) and red elderberry (Sambucus pubens Michx.).

Following the improvement of atmospheric quality in 1972, several grasses began to invade the barrens in a limited way. These included tickle grass, which invaded moist depressions and valley bottoms, as well as forming an understory to such woody relicts as white birch and blueberry. Even more striking was invasion of moist sites by tufted hair grass (Cox & Hutchinson 1981), shown by Cox & Hutchinson (1980) to be tolerant of many metals. Other graminoid colonists have included redtop and Canada bluegrass (Poa compressa L.), shown to have evolved some metal tolerance by Hogan & Rauser (1979) and by Rauser & Winterhalder (1985), respectively.

The floodplains of creeks, as well as some wet depressions, were colonized by sedges, especially Carex aenea Fern. and wool sedge (Scirpus cyperinus (L.) Kunth). Another common colonist of such sites is the balsam willow (Salix pyrifolia Anderss.). On barren peat areas, the first colonizer is often a rush (Juncus brevicaudatus (Engelm.) Fern.), followed by tickle grass in drier areas and wool sedge in wetter sites.

Almost 10 years after the closure of the Coniston smelter, white birch seedlings began to appear on bare stony slopes within a kilometre of the plant. Presumably, during this time the free acid had been washed out of the soil leaving only exchangeable acidity, since the pH has been seen to rise as much as one unit of pH (from 3.5 - 4.0 to 4.0 - 5.0) in that area. It is also possible that some of the surface metal has been eroded or leached away, or washed deeper into the profile, while near the active smelters there is still some acid loading (Cox & Hutchinson 1981). Even during 1977-1978, Cox & Hutchinson (1981) found a higher rate of spread in tufted hairgrass near the Coniston smelter than near the active smelters.

One of the more surprising colonists of barren land has been dwarf birch, normally found in fens (John Jeglum, GLFRC, Sault Ste. Marie - personal communication), but in Sudbury moving up barren hillsides, especially in seepage areas or where the effectiveness of precipitation is enhanced by runoff from rock outcrops. The only native nitrogen-fixer found as a sporadic colonist of untreated barrens is the Sweet Fern (Myrica asplenifolia L.).

Although natural recolonization is occurring, there are several reasons why the Sudbury barrens require some "assistance" to the natural process:

1. Colonization is slow, and confined to specific areas.
2. A very limited number of species colonize, giving low diversity. There is little likelihood that the primary colonists will be followed by species that would normally form part of a succession on, say, logged and burned-over land.
3. The longer an area remains unvegetated, the more the soil will be eroded.
4. The Regional Municipality is anxious to "green" the highway view-corridor, in order to enhance the region's image.
5. Liming of land improves ground water and stream water quality. Skraba and Winterhalder (1986) have shown that ground water and stream water pH are raised by surface-liming a small watershed, while the levels of copper, nickel and aluminum in the water are depressed.
6. Liming of land reduces the amount of metal taken up and cycled by any plants that grow on the soil. Winterhalder et al. (1984) showed that copper, nickel, and aluminum levels were reduced in leaves of tufted hairgrass, red pine, and jack pine following surface limestone application.

COLONIZATION OF GRASSED, SANDY BARREN VALLEY-BOTTOMS

In August 1974, 2.5 ha of fine sandy barren soil in Coniston Creek valley, with a pH of 4.0 and a total copper and nickel content of 450 and 500 mg/kg respectively, was grassed. The area was scarified with a spike harrow, limed with 1,400 kg/ha dolomitic limestone, fertilized with 350 kg/ha 7-7-7, surface-seeded with 45 kg/ha Canada bluegrass seed, and re-scarified. Within a year, the area was invaded by redtop and Alsike clover (Trifolium hybridum L.), presumably from nearby roadsides. In later years, parts of the site were invaded by woody plants such as white birch, trembling aspen, pussy willow (Salix humilis Marsh.), and sweet fern, the latter being an actinorrhizal nitrogen-fixer. Other interesting native plants that colonized spontaneously were ground orchids known as ladies' tresses (Spiranthes cernua (L.) Rich. and S. gracilis (Bigel.) Beck.) and leather grape fern (Botrychium multifidum (Gmel.) Rupr.).

A full species list is available from the author on request.

Table 2 shows the change in percent frequency of the more important species at this site over a 10-year period following grassing, based on repeated measurement of 400 1-m^2 quadrats.

Table 2. -- Percent frequency of selected species growing on a sandy site grassed with Canada bluegrass in August, 1974.

Species	Year '75	'77	'79	'80	'81	'82	'83
MOSSES							
Pohlia nutans (Hedw.) Lindb.	0	53	57	50	77	59	50
Polytrichum commune Hedw.	0	11	24	32	42	48	48
GRASSES AND SEDGES							
Agrostis gigantea	8	26	69	75	84	82	75
Agrostis scabra	4	5	13	5	14	nd	3
Carex aenea	12	6	7	5	5	4	0.3
Poa compressa	nd	nd	89	76	90	87	81
OTHER MONOCOTYLEDONS							
Spiranthes spp.	0	0	0	0	0	5	10
HERBACEOUS DICOTYLEDONS							
Anaphalis margaritacea (L.) C.B. Clarke	0.7	2	12	16	35	59	60
Solidago spp.	0	0	0	0	0.6	9	27
Trifolium hybridum	8	15	24	46	52	55	57
WOODY SPECIES							
Betula papyrifera	0	0	0	0.6	2	4	5
Myrica asplenifolia	0	0	0	0	2	4	5
Populus tremuloides	0	8	8	13	17	17	21
Salix spp.	21	21	28	35	43	36	43

nd - not determined

While table 2 gives an indication of the rate of spread of colonizers, table 3 gives a better idea of the actual increase in importance of selected species in the community as measured by percent cover.

Table 3. -- Percent cover of selected species growing on a sandy site seeded with Canada bluegrass, August 1974.

Species	Year '75	'77	'79	'80	'81	'82	'83
MOSSES							
Pohlia nutans	nd	nd	3	5	9	9	12
GRASSES AND SEDGES							
Agrostis scabra	0.4	0.5	1	0.5	2	0.7	0.3
Poa compressa	nd	nd	3	6	3	3	4
HERBACEOUS DICOTYLEDONS							
Anaphalis margaritacea	nd	nd	0.2	0.6	0.8	2	3
Solidago spp.	nd	nd	0	0	0.1	1	3
Trifolium hybridum	nd	nd	0.8	5	4	5	6
WOODY SPECIES							
Betula papyrifera	nd	nd	0	0.1	0.2	0.4	0.5
Myrica asplenifolia	nd	nd	0	0	0.4	1	4
Populus tremuloides	nd	nd	0.1	0.5	0.6	1	3

nd - not determined

The single species used, Canada bluegrass, was chosen because of its drought-tolerance and its suitability for sandy soils. Whereas in a site with more diverse microhabitats the use of a single species would be unwise, the establishment of a single species on a homogeneous site can clearly constitute an adequate trigger factor to further colonization. Canada bluegrass is a particularly suitable species for this purpose since its rhizomatous habit not only binds the soil, but it also gives a relatively open sward, allowing colonization by volunteers to occur.

COLONIZATION OF STONY SLOPES SOWN TO A GRASS-LEGUME MIXTURE

The approach used on the sandy valley-bottom was only possible because of the flatness and accessibility of the terrain. A study of the highways and railways entering Sudbury, sponsored by the Regional Municipality in 1974 (Winterhalder et al. 1975), showed that 10% of the highway margin mileage was barren, 20% very damaged, and 40% perceptibly damaged. Most of the barren land consisted of steep, eroded slopes with a cover of stones left behind as the fine material was washed away, with frequent rock outcrops.

In spite of the surface erosion that had occurred, these soils were still acid, metal-contaminated, and phytotoxic. Earlier attempts to revegetate these steep, stony slopes (Peters 1978) had required the use of heavy landscaping machinery, and were too expensive to use on a large scale. It was believed that in order to establish plants, it would be necessary to till the soil so as to bring some of the less toxic material from the subsoil to the surface. However, the author's trials initiated in 1974 showed that the surface application of ground limestone, fertilizer, and seeds was effective in establishing plant cover, the stones on the surface acting as an effective mulch and preventing the washing away of seeds and ameliorants. The experimental phase eventually gave way to a large-scale job-creation programme, in which over 2,500 ha of land were grassed, and 1,200 students and 1,600 unemployed adults were employed in a 5-year period (Lautenbach 1985).

The seed mixture used varied somewhat from year to year, but its composition during the 1983 and 1984 programmes (table 4) is typical.

Table 4. -- Percent composition by weight of the 1983 and 1984 Regional Land Reclamation seed mixtures.

Species	Percent in mixture
GRASSES	
Redtop	20
Timothy (*Phleum pratense* L.)	20
Canada bluegrass	15
Kentucky bluegrass (*Poa pratensis* Schreber)	15
Creeping red fescue (*Festuca rubra* L.)	10
LEGUMES	
Alsike clover	10
Birdsfoot trefoil (*Lotus corniculatus* L.)	10

Following the first seeding in 1978, a study carried out in the summer of 1979 showed the distribution of cover classes seen in table 5.

Table 5. -- Frequency distribution of Domin classes on grassed stony hillsides, July 1979, as determined by 1-metre-square quadrats.

Cover class	Number of quadrats
Bare	10
Less than 4% (reduced vigour)	10
Less than 4% (1 or two individuals)	8
Less than 4% (several individuals)	5
Less than 4% (numerous individuals)	30
4 - 10%	70
11 - 25%	108
26 - 33%	42
34 - 50%	68
51 - 75%	62
76 - 90%	13
91 - 100%	5

Note that 25% of the sample plots had a plant cover of between 11% and 25%, while 80% of the plots had a plant cover between 0 and 50%. The open sward created is beneficial for colonization, offering numerous openings and microhabitats for volunteer seedlings.

One of the striking aspects of the colonization of stony slopes seeded with a grass-legume mixture is the rapid colonization by woody plants, especially trembling aspen,white birch, and willows.The seed source for these woody plants lies in the frequent relict individuals that are found in the barrens. The subject of the role of these relics is discussed more fully in Winterhalder (1987a). Early herbaceous colonizers include yarrow (*Achillea millefolium* L.), pearly everlasting, and *Carex aenea*. Also striking is the increasing importance over time of one of the sown legumes - birdsfoot trefoil. This species is sown at a relatively low rate (11 kg/ha), and is rather slow in becoming established, but it spreads rapidly once establishment occurs. The rapid spread of birdsfoot trefoil suggests that it is highly suited to the terrain and is actively fixing nitrogen. A preliminary survey of soil nitrogen status, however, shows little buildup of nitrogen in the soil itself within the first few years (Winterhalder 1987b).

Table 6 shows the changes that are occurring on these revegetated barren slopes.

Table 6. -- Importance values* for selected species over a 5 to 6 year period following limestone/fertilizer/grass-legume seed treatment of stony slopes.

Species	Number of years after seeding					
	1	2	3	4	5	6
Populus tremuloides	0.0	0.9	3.1	3.9	5.7	nd
Anaphalis margaritacea	nd	0.2	0.3	1.1	1.2	3.4
Lotus corniculatus	nd	1.0	7.0	10.0	15.0	21.0
Agrostis gigantea	nd	34.0	20.0	18.7	11.0	9.0

* (Relative Frequency + Relative Cover + Relative Density) / 2
nd - not determined

The major seeded grass species, redtop, can be seen to decrease in importance over time. Whereas the gradual reduction in importance of this introduced grass might be considered desirable, and the reduction in *relative* importance of herbaceous species as woody cover increases is to be expected, the rapid loss of grass cover may be a source of concern. The fear is that the development of a woody community with bare patches between the trees might initiate the erosion cycle once more. In fact, there is evidence (table 7) that in the first few years following seeding, mean percent cover increases as a result of the growth of colonists, but the frequency of low-cover patches also increases. However, the presence of tree roots and of leaf litter will almost certainly mitigate against erosion, so long as the unvegetated patches are not too large.

Table 7. - Changes in plant cover, measured in July, on revegetated sites near Coniston (seeded in 1978).

Year	Most frequent cover class	Mean % cover ± s.d.	Number of samples
1979	11 - 25%	nd	376
1980	11 - 25%	15.1 ± 11.7	199
1981	4 - 10%	15.5 ± 13.8	198
1982	0 - 9%	17.8 ± 15.2	199

nd - not determined

Another concern is the fact that colonization by woody species is so far confined to birch, poplars and willows. In the case of maple, for which ample seed sources exist from stunted individuals on the barrens, seeds germinate on grassed land, but rarely survive the heat of the summer. It appears that soil detoxification is not at a level at which red maple seedlings can become fully established. Even the coppiced relict maples seem beyond salvation in most areas. Without soil amelioration they show a steady year-by-year regression, in which large stems die and are replaced by smaller stems. Following soil amelioration there is some evidence of partial recovery, but this does not appear to be universal. Although there is not, so far, any evidence of oak recruitment from relics on grassed land, there is some evidence of this in untreated scrub-oak woodland south of Skead, where relict oak is dominant. Another group of woody species that has so far shown little sign of colonization is the conifers. In this case, the seed source is more limited, and suitable seed bed conditions are rare. For this reason, such species as red pine, jack pine, and white pine are planted in groups (see abstract by Beckett in these Proceedings) to act as a seed source for future natural ecosystem development. In addition, some exotic tree species such as European larch (Larix decidua Mill.) and black locust (Robinia pseudo-acacia L.) are also planted, raising controversial questions concerning the advisability of using exotics when the creation of a quasi-natural plant community is the stated aim (Winterhalder 1987a).

The reason for planting black locust is a rather special one: Like the clover and trefoil used in the seed mixture, it is a nitrogen fixer, and it has been highly successful wherever it has been planted. The only native nitrogen-fixer to spread effectively following treatment is sweet fern, which occurs occasionally on barren land and spreads quickly once the land is treated. Unfortunately the native alders (Alnus rugosa (Du Roi) Spreng. and Alnus crispa (Ait.) Pursh.), although producing winged seeds similar to those of white birch, do not readily volunteer on revegetated land. Experimental planting of alder container stock has recently been initiated. Small-scale transplants of another native nitrogen-fixing shrub, soap buffalo berry (Shepherdia canadensis (L.) Nutt.) from Manitoulin Island have been highly successful, as have those of bearberry (Arctostaphylos uva-ursi (L.) Spreng.). Although the latter species is not normally considered to be a symbiotic nitrogen fixer, it has been reported as nodulated in Alaska (Sprent 1979). The green vigorous growth of this ground-cover-forming species causes the author to suspect some form of symbiotic nitrogen fixation, possibly rhizosphere-based. The question is under investigation.

LIMING AS A TRIGGER FACTOR

When a thin sprinkling of ground limestone is applied to the surface of a barren soil, colonization occurs rapidly. Preliminary evidence points to the existence of a small persistent seed bank, but it appears that most of the seedlings arise from seeds that are blown in following liming. Table 8, from Winterhalder (1985), summarizes the results of colonization over a 5 to 6 year period of twelve 1-m^2 plots, the surface of which had been lightly sprinkled with pulverized limestone.

Table 8. -- Importance values (Cover/Frequency Index*) for species colonizing twelve limed 1-m^2 plots over a 5 to 6 year period.

Species	Mean % Cover	% Frequency	Importance Value
WOODY			
Betula papyrifera	41.3	66.6	47.5
Salix spp.	3.6	50.0	11.5
Populus tremuloides	3.3	41.7	9.8
P. grandidentata Michx.	0.8	8.3	2.1
HERBACEOUS			
Agrostis scabra	5.6	83.3	18.8
Rumex acetosella L.	1.3	8.3	2.5
Aralia hispida Vent.	0.8	8.3	2.1
Conyza canadensis (L.) Cronq.	0.1	8.3	1.5
Festuca rubra **	0.1	8.3	1.5
Phleum pratense **	0.1	8.3	1.5
Poa compressa **	0.1	8.3	1.5

* (Relative Frequency + Relative Cover) / 2
** From seeds blown in from nearby revegetated area

Some mortality occurs following initial germination on limed areas. As the percent cover of woody plants like white birch increases, the numbers decrease through competition. Frost action, which is enhanced on these barren sites (Sahi 1983), also plays a part in the mortality of small seedlings. Table 9 shows the effect of frost-heaving on the seedlings in a single 1-m^2 plot near Coniston, as observed June 4, 1981.

Table 9. -- Frost-heaving and mortality in seedlings on limed plots near Coniston.

Species	Total number of living seedlings	Number of living seedlings showing signs of heaving	Number of dead seedlings (all species)
Salix spp.	81	36	
Populus tremuloides	6	0	
Betula papyrifera	2	0	
Agrostis scabra	64	2	
All species	153	36	44

The overwinter mortality of woody seedlings was 33%, while 41% of the surviving seedlings showed signs of frost-heaving. Tickle grass is heaved very little, presumably because of its fibrous root system, and it almost certainly plays a role in stabilizing the soil and reducing the amount of heaving in woody seedlings.

IS SEEDING NECESSARY OR DESIRABLE?

This question has arisen as a result of the trigger factor effect mentioned above. If the application of limestone alone is sufficient to initiate plant growth, then a number of arguments could be produced favouring the elimination of fertilizing and seeding as now practiced. There would be an evident economic advantage to this approach, while from the ecological standpoint it could be argued that the introduction of exotics should be avoided wherever possible. The idea of creating a woodland with an understory of agronomic grasses may at first seem to be ecologically inappropriate. In actuality, however, there is a tendency for woody species to become more important and herbaceous species less important during the years that follow grassing (Winterhalder 1985). The potential benefits of the legumes in the seed-mixture to the growth of woody plants should also be remembered. In one of the more successful pine plantations on revegetated land, near Wahnapitae, there is a dense understory of birdsfoot trefoil, and both conifer and legume seem to be thriving.

Another point for consideration is the difference in colonizer spacing between seeded and non-seeded areas, and the effect on later competition. If the grass-legume mixture is established as an open community, as practiced in Sudbury's Regional Land Reclamation Programme, then the woody plants that colonize will be found in a somewhat random arrangement, with spaces between the seedlings. If, however, the site is limed only, then the colonizing birches, willows, and poplars form a dense stand that will lead to vigorous competition until certain individuals can achieve dominance. This phenomenon is shown in table 10, where the woody plants on two 1000-m^2 plots (one limed, fertilized and seeded, the other merely limed) are recorded.

Table 10. - Percent Cover and Importance Value (Cover/Frequency Index*) achieved in 2 years by woody colonizers on a limed, fertilized, and seeded plot and on a unseeded, unfertilized, limed plot.

Species	Seeded Plot		Unseeded Plot	
	% cover	IV	%cover	IV
Populus tremuloides	0.6	1.5	9.1	29.1
Salix spp.	0.1	0.9	5.5	20.1
Betula papyrifera	0.0	0.0	0.4	4.5
Populus grandidentata	0.0	0.0	0.0	3.2

*(Relative Frequency + Relative Cover/2

SUMMARY AND CONCLUSIONS

It has been shown that the surface application of ground limestone to acid, metal-contaminated, barren soils in the Sudbury area detoxifies the soil and allows plant growth. If limestone is applied alone, a cover of mostly woody plants develops. If grass seed is also applied, other species, including legumes, will eventually colonize. In practice, limestone, fertilizer, and a grass-legume seed mixture are applied manually to the surface of stony barren slopes. Within a few years the treated land bears a rich mixture of herbaceous and woody species, with seeded legumes and woody species increasing in importance over time.

Image improvement through revegetation of highly visible barren land is a declared policy of the Regional Municipality. To quote the Region's Official Plan (Lautenbach 1985):

> "It shall be the policy of the Council to . . . . Give priority initially to reclamation projects in those areas where the results would be immediate, dramatically obvious and economically feasible. This includes areas which are most visible to the public, such as major transportation corridors and locations surrounding public facilities."

For this reason, revegetation efforts so far have been confined to highway view-corridors. Because of the visibility of the land and the need for an instant "cosmetic" effect, the potential for allowing natural revegetation to occur following minimal amelioration (i.e., limestone only) has not been fully exploited. Even on grassed land, however, volunteer colonization has given rise to a diverse plant cover with a strong native component.

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HABITAT USE BY SELECTED SMALL MAMMALS OCCURRING IN SURFACE MINE CATTAIL MARSHES[1]

Cheryl R. Amrani and David E. Samuel[2]

Abstract.--Little information is available regarding the wildlife value of cattail marshes on surface mines. Small mammals may increase the value of reclaimed surface mines because they serve as major prey items for terrestrial and avian predators. Small mammals were sampled in 12 cattail marshes and on 12 nearby grassy comparison sites on surface mines. Six trap samples were conducted between October 1985 and April-May 1987 in Monongalia County, WV and Greene County, PA. A total of 157 *Peromyscus* were captured during the study period. Significantly ($p < .05$) greater numbers of *Peromyscus* were taken in cattail marshes (111) than on camparison sites (46). Breeding adults accounted for 30% of the marsh captures, compared to 26% of the *Peromyscus* captured on nearby comparison sites. A total of 76 meadow voles were captured during the study period. Equal numbers of meadow voles were captured in cattail marshes and on comparison sites. However, breeding adults accounted for 32% of the marsh captures, compared to 15% of those meadow voles captured on comparison sites. This sampling demonstrated that cattail marshes provide additional small mammal habitat on surface mines, and that *Peromyscus* prefer surface mine cattail marshes over grassy comparison sites.

INTRODUCTION

McConnell and Samuel (1985) documented the use of surface mine cattail marshes by a variety of birds and small mammals. As a major prey item in the diets of many avian and terrestrial predators (Linduska 1950, Craighead and Craighead 1956, Dexter 1978, Hockman and Chapman 1983), small mammals increase the habitat value of reclaimed surface mines for such predators (Yearsley 1976, Mindell 1978, Forren 1981). They may therefore provide an index to the wildlife value of cattail marshes on reclaimed surface mines. The objective of this study was to determine the relative use of cattail drainages and grasslands by small mammals on reclaimed surface mines and lands affected by surface mining.

Acid mine drainage affects about 17,600 km of streams in the United States. A majority of those streams impacted by iron- and manganese-containing acid runoff occur in the Appalachian coal mining regions (National Research Council 1979). Such water can be chemically neutralized but recently circulation of acid drainage through natural and manmade wetland has been suggested (Kleinmann et al. 1983, Burris et al. 1984, Wieder and Lang 1984, Holm and Jones 1985, Girts and Kleinmann 1986).

Cattails have value in treating acid mine drainage (Snyder and Aharrah 1984, McConnell and Samuel 1985, Kleinmann 1987). Although there is also substantial evidence that Appalachian wetlands, including cattail marshes, have significant wildlife value

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(Evans and Wilson 1982, Udevitz and Michael 1982, Rewa 1984), little is known about the value of cattail marshes on surface mines. Cattail marshes are a naturally occurring by-product of surface coal-mining activities (Klimstra and Nawrot 1985). The opportunity now exists to incorporate cattail marsh construction into surface mine reclamation as a passive mine drainage treatment. The added value of enhancement to wildlife would encourage such a consideration.

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STUDY AREAS

Twelve cattail sites were located on mined lands or lands affected by surface mining in Monongalia County, WV and Greene County, PA. Twelve grassy sites (hereafter called comparison sites) were trapped for comparison purposes. Comparison sites were the same size and shape as the cattail sites to which they were compared and were selected to represent as closely as possible the environmental characteristics affecting each cattail site. Each comparison site was located at least 100 m from the cattail site to which it was compared.

There were six cattail sites and six comparison sites on King Knob Mine (Monongalia County, WV). They varied in size from .024-.10 hectaces and were mined prior to the Federal Surface Mining Control and Reclamation Act of 1977. There were two sites (.008 hectaces and .104 hectaces, respectively) located on the active Dippel and Dippel Mine in Monongalia County, WV. Two additional Monongalia County sites were .012 hectaces receiving runoff from a reclaimed mine upslope and a .068-hactare site located in an old sediment pond for a depp mine. In Greene County, two additional 0.1-hectare sites were selected from a 1.6-hectare rectangular cattail marsh. This area had never been mined, but received drainage from an unreclaimed surface mine.

Eight cattail sites and their respective comparison sites were bordered by deciduous woods on at least one side. Open areas of standing or running water were present in nine of the cattail sites at least part of the year. Ten of the cattail sites had cattail densities greater than 10 stems/m^2 and nine had densities greater than 13 stems/m^2. Vegetative cover was greater than 50% on nine of the comparison sites. Of these, three were mowed regularly.

METHODS

Small Mammal Census

Small mammals were sampled by the snap-trap removal method (Brower and Zar 1977) during October 1985, May, July, and October 1986, and April-May 1987 on all cattail and comparison sites. Additional sampling was conducted only in Greene County, PA during February 1987. A peanut butter and oatmeal mxiture was used as bait (Beer 1964). Initially, trapping stations were 10 m apart. This was changed to a 5-m^2 grid in July 1986 to increase capture probabilities. Three traps per station were monitored for three successive nights during each trapping period. The total number of traps set in the cattail marshes each trapping period varied with grid size and wetland water levels (i.e., fewer trap stations were available during flooded conditions). The number of traps set in comparison areas were adjusted accordingly.

Vegetative Cover

Cattail densities were calculated as the simple average of 10 randomly placed 1-m^2 plots in each cattail site. Herbaceous cover on the comparison sites was measured by ocular estimate.

Statistics

The small mammals captured in the present study do not represent a random sample, but rather a convenient sample taken within budgetary, time, and effort constraints. Captures from all sites in each treatment group were pooled by species to achieve a sufficient sample size for statistical application. The small sample sizes available and the inequality of numbers of animals captured at different sites create ambiguity as to the applicability of statistical testing. It may be hypothesized, however, that if a truly random sample were taken similar results would be achieved.

Wilcoxon's signed rank test for non-normal samples (Hollander and Wolfe 1973) was used to describe small mammal preferences for cattail drainages on surface mines. Insufficient sample size precluded the use of statistics to describe seasonal differences in habitat preferences. Only significant ($p < .10$) results are reported. Considering the assumption violations inherent in this sample, statistical inference is inappropriate. Significance is reported for descriptive purposes only, and trends will be discussed.

RESULTS AND DISCUSSION

General

A total of 76 meadow voles and 157 *Peromyscus* were captured during 6 trapping periods between October 1985 and April-May 1987 (table 1). Smaller numbers of short-tailed shrews (*Blarina brevicauda*), meadow jumping mice (*Zapus hudsonius*), and and house mice (*Mus musculus*) were also caught throughout the study period (table 2). Total small mammal captures over the study period were significantly ($p < .05$)

Table 1.--Number of meadow voles and *Peromyscus* caught during six trapping periods between October 1985 and April-May 1987.

	Number of Meadow Voles		Number of Peromyscus	
	Cattails	Comparison Sites	Cattails	Comparison Sites
Oct 1985	19	18	11	16
May 1986	1	2	6	6
Jul 1986	8	6	31	12
Oct 1986	6	5	46	11
Feb 1986	0	0	11	0
Apr-May 1987	4	7	6	1
TOTAL	38	38	111	46

Table 2.--Total numbers of short-tailed shrews, meadow jumping mice, and house mice captured during six trapping periods between October 1985 and April-May 1987.

	Cattail Sites	Comparison Sites
Short-tailed shrew	20	33
Meadow jumping mouse	5	5
House mouse	9	0
TOTALS	34	38

greater on cattail marshes than on comparison sites.

The number of meadow vole and *Peromyscus* captures in each period reflected a generally decreasing trend in trap success rates throughout the study period (table 3). This decreasing trend in trap success during the study period may reflect the cyclic nature of many small mammal populations (Krebs and Meyers 1974, Gunderson 1976, Wolff 1985a). Seasonal weather extremes may exacerbate cyclic trends. Environmental stresses may also participate in reducing small mammal populations. In a concurrent study (Amrani 1987) it was found that iron levels in the tissues of some small mammals are correlated with iron levels in soil samples taken from capture sites. Iron absorption, retention, and toxicity are age-related (Gruden 1986, Klassen et al. 1986), increasing with decreasing age. Increased susceptibility of subadults to metal toxicity could have serious impacts on population structure.

Peromyscus

Peromyscus captures in cattail marshes totalled 111, compared with 46 captures on comparison sites (table 1). Significant differences ($p < .05$) between habitat types occurred during all trapping periods except October 1985, a period of peak *Peromyscus* densities during this study. In all cases preference was shown for cattail sites.

Mindell (1978) reported that small mammal densities on reclaimed surface mines were positively correlated with percent of vegetative cover. Less than 50% vegetative cover on three of the twelve comparison sites may have decreased use of comparison sites. Mowing practices reduced vegetative cover on three additional comparison sites. *Peromyscus* using habitat with little vegetative cover would be easy targets for predators occupying reclaimed surface mines (Yearsley 1976, Mindell 1978, Forren 1981). This was a good possibility on the Greene County sites where there was an active fox den throughout the study

Table 3.--Trap success rates (no./100 trap nights) for meadow voles and *Peromyscus* caught during the six trapping periods between October 1985 and April-May 1987.

	Meadow Voles		*Peromyscus*	
	Cattails	Comparison Sites	Cattails	Comparison Sites
Oct 1985	.051	.048	.030	.0430
May 1986	.003	.006	.019	.0170
Jul 1986	.005	.003	.018	.0070
Oct 1986	.003	.003	.025	.0060
Feb 1986	--	--	.025	.0000
Apr-May 1987	.002	.004	.003	.0005

period.

Eight of the cattail marshes and their comparison sites were adjacent to wooded areas. All of these were within home range estimates reported for *Peromyscus* (Blair 1940, Wolff 1985b). There were no observable differences between amount of woodland perimeter around cattail and comparison sites. McConnell and Samuel (1985) suggested that deer mice moved into cattail marshes from adjacent woodlands. They reported no similar movement into grass-legume fields. White-footed mice occupying adjacent woodlands may be attracted to the vertical structure of cattail sites (Sheppe 1966, Barry et al. 1984).

Cattail marshes may also provide small mammals a protective microclimate. The thermoneutral zones of *Peromyscus* are very narrow. A milder, moister habitat may mitigate thermo-regulatory and water regulation requirements of *Peromyscus* (Hill 1983, MacMillen 1983).

Subadults accounted for only 8% of all *Peromyscus* captured in cattails from May 1986 to April-May 1987 compared to 20% on comparison sites during the same period (table 4). Linduska (1950) reported 95% of all *Peromyscus* examined in October-November were subadults. During October 1986, 10% of all *Peromyscus* captured in cattail marshes were subadults, compared to 66% on comparison sites. Burt (1940) reported that 51 of 154 young white-footed mice moved between 100 and 900 yds from the place of first capture. Considering the small size of many of the cattail sites in this study, it is possible that subadults dispersed from cattail marshes into adjacent grasslands thereby inflating the number of subadults on comparison sites.

Breeding adults accounted for 30% of all captures on cattail sites compared to 26% on the comparison sites during this period (table 5). However, only one breeding adult from the comparison sample was female, compared with ten from the cattail sample. Linduska (1950) reported 40% of adult female *Peromyscus* examined in October-November to be in breeding condition. It is therefore apparent that *Peromyscus* were using cattail marshes as breeding habitat.

Meadow Voles

Total numbers of meadow voles captured on cattail sites equaled total numbers captured on comparison sites (table 1). No significant differences were found between habitat types during any trapping period. This is not surprising since meadow voles are reported to inhabit lush grassy fields, as well as marshes, swamps, and woodland glades (Whitaker 1980).

McConnell and Samuel (1985) found no differences in meadow vole captures on cattail and grass-legume sites during July 1984. However, they reported increased meadow vole densities in cattail marshes on surface mines during the spring and autumn of that year. Their study was conducted during a period of low annual rainfall (D.E. Samuel, personal communication). Udevitz and Michael (1982) found significantly ($p < .05$) more meadow voles on cattails sites than in the uplands during the summer, but no difference the previous summer. Weather conditions were not reported.

The advantages of protective microhabitat discussed above apply equally well to meadow voles. It is possible that an ameliorating microclimate may increase meadow vole densities in marshes during weather extremes (McConnell and Samuel 1985). Cattail marshes may provide little microclimate advantage during extremely dry summer months when water sources dissipate.

Table 4.--Demographic characteristics of Peromyscus caught in cattail marshes and on comparison sites during five trapping periods from May 1986 to April-May 1987.

	Subadult		Adult		Undetermined
	Male	Female	Male	Female	
			CATTAILS		
May 1986	1	2	2	3	0
Jul 1986	0	0	15	9	7
Oct 1986	1	3	20	19	4
Feb 1986	0	0	5	6	0
April-May 1987	1	0	1	0	0
TOTALS	3	5	43	38	11
			COMPARISON SITES		
May 1986	1	0	1	2	0
Jul 1986	1	0	6	5	0
Oct 1986	2	2	3	3	0
Feb 1986	0	0	0	0	0
April-May 1987	0	0	3	1	0
TOTALS	4	2	13	11	0

Table 5.--Number of breeding adult *Peromyscus* caught in cattail marshes and on comparison sites during five trapping periods from May 1986 to Apirl-May 1987.

	Cattails		Comparison Sites	
	Male	Female	Male	Female
May 1986	0	0	0	0
Jul 1986	15	0	6	1
Oct 1986	3	7	0	0
Feb 1987[a]	0	0	-	-
April-May 1987	2	3	1	0
TOTALS	20	10	7	1

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[a] No *Peromyscus* were caught on grasslands during this period.

Table 6.--Demographic characteristics of meadow voles caught in cattail marshes and on comparison sites during five trapping periods from May 1986 to April-May 1987.

	Subadult		Adult		Undetermined
	Male	Female	Male	Female	
			CATTAILS		
May 1986	0	0	1	0	0
Jul 1986	0	0	3	3	0
Oct 1986	0	2	2	2	2
Feb 1987	0	0	0	0	0
April-May 1987	0	1	0	3	0
TOTALS	0	3	6	8	2
			COMPARISON SITES		
May 1986	1	0	1	0	0
Jul 1986	0	2	2	4	0
Oct 1986	0	2	1	1	0
Feb 1987	0	0	0	0	0
April-May 1987	1	0	3	1	0
TOTALS	2	4	7	6	0

Table 7.--Number of breeding adult meadow voles caught in cattail marshes and on comparison sites during five trapping periods from May 1986 to April-May 1987.

	Cattails		Comparison Sites	
	Male	Female	Male	Female
May 1986	1	0	0	0
Jul 1986	2	2	0	1
Oct 1986	0	1	0	0
Feb 1987[a]	-	-	-	-
April-May 1987	0	0	0	2
TOTALS	3	3	0	3

[a] No meadow voles were caught during this period.

This may explain inconsistencies in summer meadow vole densities in cattails during different years.

Subadult meadow voles on cattail sites accounted for 16% of marsh captures, compared with 10% on comparison sites (table 6). Breeding adult voles accounted for 32% of the marsh captures and 15% of the captures on comparison sites (table 7). All breeding adults from comparison sites were female. Sexes were equally divided among breeding adults in cattail marshes.

Cattail marshes green up earlier in the spring, often remain moist and productive during dry summer months, and are not subject to regular mowing schedules. The additional food available in highly productive marsh habitat may favorably influence the demographic characteristics of meadow vole populations. Desy and Thompson (1983) reported greater numbers of breeding adults on sites artificially supplemented with additional food (high proteinPurina mouse chow) than on controls. They also reported larger numbers of juvenile voles during autumn on food-supplemented sites.

CONCLUSIONS

Cattail marshes on surface mines provide additional habitat for meadow voles. Reproductive parameters are higher for meadow voles caught in cattail marshes than for those from grassy comparison sites. Peromyscus prefer cattail habitats on surface mines over grassy areas. Marshes adjacent to woodlands provide additional vertical structure and overhead cover. Peromyscus use cattails as breeding habitat. Additional investigations may conclude that cattails are used preferrentially for breeding.

Marshes provide a moist, moderate microclimate which enhances productivity. High food availability, good vegetative cover, and a protective microhabitat create a suitable environment for small mammal populations.

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FIRST YEAR EVALUATION OF MITIGATED WETLANDS ON TWO MINE SITES IN WESTERN PENNSYLVANIA[1]

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Abstract.--Twenty-two hectares (56 acres) of wetlands were established on two (Guarnieri abd Edwards) mine sites in western Pennsylvania at approximately the same cost that would have been incurred if the land had been returned to approximate original contour (AOC) according to current regulations. Of the 833 plants comprising 24 species that were found on 22 quadrates of the Guarnieri Mine, 752 or 90.3 percent and 19 species were volunteers, while on the Edwards Mine a total of 127 individual plants comprising 9 species occurred on the five quadrates. Of these, 63 or 40.6 percent comprising 7 species volunteered on this wetlands. The density of plants averaged $37/m^2$ and $25/m^2$ on the Guarnieri and Edwards Mines, respectively. During the first year over 40 species of wildlife, including six species of special concern in Pennsylvania, used these wetlands for some phase of the life history. These wetlands provide additional ecological diversity to the mine sites, and the excellent response by wildlife to these areas will enhance the overall ecology of the region.

INTRODUCTION

For over four decades, wetlands have been left as an aftermath of surface coal mining, especially in the eastern (Brenner and Steiner 1987) and midwestern (Jones et al. 1985) coal regions of the United States. These wetlands provide habitat for a variety of wildlife species, including amphibians (Brooks et al. 1985, Fowler et al. 1985), reptiles (Brooks et al. 1985), birds, and mammals (Brenner and Kelly 1981, Brenner et al. 1982, Brooks et al. 1985). In both the East and Midwest, several studies have documented the use of these wetlands by nesting waterfowl and shorebirds (Brenner 1973, Brenner and Mondok 1979, Sandusky 1978, Thompson 1984) as well as their use for resting and feeding during migration (Brenner and Steiner 1987). In addition to their value as wildlife habitats, many of these wetlands support valuable warm water fisheries (Brenner 1983).

Although these wetlands have been shown to be used extensively by wildlife, they were often left as an afterthought with little if any planning for their integration into the overall reclamation of the site. The primary objective of this paper is to describe and discuss how different types of wetlands may be integrated into the overall reclamation of mined lands as well as what additional costs may be incurred by coal companies. For over a decade, I have advocated the development of wetlands on mined lands (Brenner 1973, 1983) including special areas designed for rare and endangered species (Brenner 1985, 1986). In this paper, the construction, establishment of wetland vegetation, and their use by wildlife will be discussed in light of overall ecology of reclaimed mined lands.

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A total of approximately 22.4 ha (56 acres) of wetlands was developed on two mine sites in northwestern Pennsylvania as part of a mitigation and reclamation plan developed by Adobe Mining, Inc. On the site hereafter referred to as the Guarnieri Mine, seven Palustrine and one deep water habitat totaling 19.2 ha (48 acres)($\bar{X}$ 2.4 ha, 6 acres) were developed on a 73.6 ha (184 acre) mine site to replace approximately 4.8 ha (12 acre)($\bar{X}$ 1.2 ha, 7 acre) of Palustrine wetlands on an adjacent active mine. The Palustrine wetlands consisted of a sedimentation pond, a deep water habitat, and six other areas constructed during site reclamation. Water level control devices were installed on four of the Palustrine wetlands, the sedimentation pond, and the deep water habitat so that, if necessary, water levels could be controlled for the management of aquatic vegetation. All water courses installed on the site were diverted into the wetland complex. Six of the wetlands were designed to allow excessive rainfall (25 yr. event) to overflow from the emergency spillways into the deep water habitat, which could then overflow into the sedimentation pond which in turn drained into a natural wetland complex owned and managed by the Pennsylvania Game Commission. A 0.2 ha (0.5 acre) island was constructed approximately in the center of the deep water habitat to provide additional waterfowl nesting habitat.

On a second mine site hereafter referred to as the Edwards Mine, three Palustrine wetlands totaling 3.2 ha (8 acre) were constructed to replace a 1.8 ha (4.6 acre) Palustrine wetland removed during mining of the site. The total affected area was approximately 25 ha (100 acre). As with the Guarnieri Mine, one wetland was a converted sedimentation basin and two were constructed during reclamation. All water courses were diverted into these wetlands so that adequate water levels could be maintained. One 1.4 ha (3.5 acre) Palustrine wetland was constructed with irregular shorelines along with five islands to increase the amount of edge and thereby provide additional feeding and nesting areas available for waterfowl. On both mines, nonwetland areas were planted with trees and shrubs interspersed among the grasslands (grasses and legumes) to provide additional habitats for upland wildlife species.

CONSTRUCTION

Two different procedures were used for the construction and establishment of wetlands on these sites. On the Guarnieri Mine, two wetland sites received material transported to the sites from natural Palustrine wetlands located on an adjacent active mine site. Once the upper 60 cm (24 inches) of material was removed and stockpiled at the site, the underlying clay and muck was removed, transported, and spread in the newly constructed wetland. Once this phase was completed, the stockpiled material was transported and placed in the wetland. Within five working days, the construction and transportation phase of the project was completed and water was released into the sites. These areas did not receive supplemental plantings of wetland species. This project was scheduled to be completed either in late fall or early spring when the plants would be dormant but, due to excessive delays in the permitting process, it was not completed until late April. To date, on the remaining six wetland sites, a total of 14,150 individual plants, comprising 10 different species have been planted and the areas seeded with 50 lbs of coontail (_Ceratophyllum demersum_) along with 480 lbs of grasses and legumes, all according to the hydrologic regime existing at each site (table 1). In addition, a total of 3,750 trees and shrubs representing 16 species were planted either adjacent to the wetlands or in upland areas, depending on site conditions (table 2). The total cost of supplemental plantings was $7,325 which includes $5,509 and $1,816, respectively, for plant materials and labor.

Table 1.--Varieties and quantities of wetland species planted or seeded on the Guarnieri and Edwards Mines in 1987.

SPECIES	NUMBER PLANTED/LB SEEDED Guarnieri Mine	 Edwards Mine
Sago Pondweed (_Potamogeton pectinatus_)	1000	500
Wild Cherry (_Vallisneria spinalis_)	1000	500
Arrowhead (_Sagittaria_ spp.)	1000	500
Duck Potato (_Sagittaria rigida_)	1000	500
Burreed (_Sparganium eurycarpum_)	2000	1000
Three Square Rush (_Scirpus flaviatilis_)	2000	1000
Sweet Flag (_Acorus calamus_)	2000	1000
Nodding Smartweed (_Polygonum mahlenbergh_)	2000	1000
Pickerel Weed (_Pontederia cordata_)	2000	1000
Buttonbush (_Cephalanthus occidentalis_)	150	100
Coontail (_Ceratophyllum demersum_)	50 lb	25 lb
Switchgrass (_Panicum virgatum_)	100 lb	40 lb
Reed Canary Grass (_Phalaris arundinacea_)	150 lb	60 lb
Millet (_Echinochloa crusgalli_)	100 lb	100 lb
Lespedeza Mixture (_Lespedeza_ spp.)	80 lb	40 lb

The overall reclamation costs to the company were approximately the same as would have occurred if they were approximately the same as would have occurred if they would have returned the land to the approximate original contour (AOC) as required by current regulations.

On the Edwards Mine, a natural Palustrine wetland was transported into a 1.4 ha (3.5 acre) wetland constructed on the same site. The same procedure was followed as at the Guarnieri Mine for the removal, storage, and transportation of material between the natural and manmade system except that scrapers rather than trucks were used to transport the material. Since this project was initiated in the middle of August, water from the active pit (pH 7.0-7.2) was pumped into the site as soon as all material was in place. The total time lapse from the start of the project until there was sufficient water to maintain the system was approximately 10 days. To date, a total of 9050 individual plants and 265 lb of seeds representing 27 different species have been planted on the site (tables 1 and 2). The total cost of the establishment of vegetation at this entire 3.2 ha (8 acre) wetland complex was approximately $3,772 of which $2,866 and $906 was for material and labor, respectively. As with the Guarnieri Mine, reclamation costs to the company were approximately the same as would have been incurred if the land was returned to AOC as required by current regulations.

RESPONSE OF WETLAND VEGETATION

On both mines, there was good survival and growth of vegetation on both the transplanted wetlands as well as those receiving supplemental plantings of wetland species. In order to assess the response of natural revegetation of wetland species on the Guarnieri Mine, 22 m^2 quadrates were established on five wetlands, three of which received supplemental plantings and ~~two~~ which received wetland soil and plant material from the adjacent mine site. Of the total 833 individual plants found on the quadrates (not including Nitella and Lemna minor), 752 or 90.3 percent were volunteer species. Nitella and Lemna minor had a density of approximately 15/cm^2, respectively. Nineteen of the 24 species identified on these wetlands were a result of volunteer invasions and/or from seeds or root stocks present in the material transported from the adjacent mine site. The number of species/m^2 and the density of plants/m^2 on those wetlands that received supplemental plantings did not differ from those that received the transplanted wetland material. Between 8 and 13 different species occurred on the individual quadrates receiving supplemental plantings compared to the 8 or 9 species that occurred on the transplanted sites, and the average number of plants was 36 (32-41) and 38 (23-53) individuals/m^2 for those areas that received supplemental plantings and those that received wetlands soils, respectively. The principal species occurring on all wetlands on the Guarnieri Mine included Echinochloa muricata, Eleocharis obtusa, Bidens frondosa, Panicum capillare, and Polygonium sagittatum (table 3). In addition to these species, sensitive fern (Onochlea sensiblis), skunk cabbage (Symplocarpus foetidus) along with rushes (Juncus spp.), and sedges (Carex spp.) were observed on the transplanted wetlands, but they did not occur on the randomly selected quadrates. Throughout the transplanted wetlands, numerous dogwoods (Cornus spp.), black willow (Salix nigra), and buttonbush (Cephalanthes occidentalis) were observed sprouting from root stocks present in the soil. On the wetlands that received supplemental plantings of wetland species, the species in the shallow and intermediate depth zones became established within two

Table 2. Varieties and quantities of trees and shrubs planted on the Guarnieri and Edwards Mines in 1987.

SPECIES	NUMBER PLANTED Guarnieri Mine	Edwards Mine
Red Oak (Quercus rubra)	300	200
Pin Oak (Quercus palustris)	300	100
Bur Oak (Quercus macrocarpa)	200	100
White Oak (Quercus alba)	100	—
Swamp Oak (Quercus bicolor)	200	—
Scrub Oak (Quercus ilicifolia)	200	—
Washington Hawthorne (Crateagus phaenopyrum)	300	200
Amerucan Plum (Prunus americana)	150	100
American Crabapple (Pyrus coronaria)	100	—
White Ash (Fraximus america)	—	100
Silky Dogwood (Cornus amomum)	700	300
Gray Dogwood (Cornus racemosa)	150	100
Buckthorn (Rhomnus cathartica)	200	100
European Black Alder (Alnus glutinosa)	500	500
Norway Spruce (Picea abies)	150	100
Black SPruce (Picea mariana)	100	50
Scotch Pine (Pinus sylvestris)	100	—

Table 3.--Plant species found on quadrates on wetland sites on the Guarnieri and Edwards Mines during September and October 1987.

SPECIES	NUMBER OF INDIVIDUALS	
	Guarnierei Mine	EDwards Mine
Arrow Leaved Tearthumb (Polygonium sagittatum)	45	0
Smartweed (Polygonium natens)	3	0
Water Smartweed (Polygonium obtusa)	1	0
Spike Rush (Eleocharis obtusa)	118	8
Wild Millet (Echinochloa muricata)	130	2
Bur- marigold (Bidens frondosa)*	115	19
Panic Grass (Panicum capillare)	212	16
Bur-reed (Sparganium eurycarpum)	45	3
Rice Cut Grass (Leersia oxyzoides)	5	0
Goldenrod (Solidago lepida var. elongata)	23	0
Sedge (Cyperus strigosus)	10	0
Shepherd's Purse (Capsella Bursa-pastoris)	7	0
Cup Grass (Eriochloa contracta)	31	0
Red Clover (Trifolium pratense)*	21	35
White Clover (Trifolium repens)*	2	26
Cattail (Typha latifolia)	47	2
Ragweed (Ambrosia artemisiifolia)	0	16
Arrowhead (Sagittaria spp.)*	4	0
Sago Pondweed (Potomageton pectinatus)	4	0
False Loosestrife (Ludwigia spp.)	3	0
Birdsfoot Trefoil (Lotus corniculatus)*	5	0
Pokeweed (Phytolacca americana)	1	0
Foxtail (Setaria glauca)	1	0
Musk Grass (Nitella spp.)	$15/cm^2$	$10/cm^2$
Duckweed (Lemna minor)	$74/cm^2$	0
TOTAL	752	127

*Planted during reclamation

months of planting and those in the deep zone are beginning to become established. The success of these species, however, cannot be firmly established until the end of the second growing season.

On the Edwards Mine, the response of vegetation on the site that received the transplanted material was not as rapid as it was on the Guarnieri Mine. Significant natural regeneration of wetland plants did not occur until the following spring, probably due, at least in part, to the fact that natural material was not placed into the newly constructed wetland until August. During the following spring and summer months, however, the response of those species that did regenerate naturally as well as the supplemental species in the shallow water zone showed excellent survival and growth.

In contrast to the Guarnieri Mine,only a total of nine species were present on the five quadrates and of those, two species (Trifolium pratense and T. repens) probably invaded from adjacent upland areas. A total of 127 individual plants were found on this wetland, and of these, 63 or 40.6 percent were volunteers. Between four and six species were on the individual quadrates and the average density was 25 (22-29) individuals/m^2. This wetland has a dense grass and legume cover immediately adjacent to the relocated wetland, and this dense cover, in conjunction with elevated water levels over the transplatned wetland materials, may be factors in the reduction in the number of volunteer species becoming established on this wetland.

WILDLIFE USE

Over 30 species of birds, including 5 species of special concern in Pennsylvania (Genoways and Brenner 1985) were observed using these wetlands and adjacent uplands during the first year (table 4). At least five broods of Canada geese and three mallard broods were observed using this wetland complex. During the summer months between 100-300 Canada geese and over 100 mallards, black ducks (Anas rubripes), blue-winged teal, and wood ducks, along with approximately 20 spotted sandpipers and several great blue herons and green herons (Butorides striatus) were observed feeding on these wetlands and adjacent uplands on a regular basis. The use of the Edwards Mine by wildlife was not as great as it was on the Guarnieri Mine, with only 20 species of birds including three species of special concern (Genoways and Brenner 1985) being observed using this site on a frequent basis (table 4). These wetlands were used for

Table 4.--Species of birds using the Guarnieiri adn Edwards Mines during the spring and summer months of 1987.

FAMILY	COMMON NAME	GUARNIERI MINE	EDWARDS MINE
Ciconiiformes	Great Blue Heron - *Ardea herodias**	X	X
	Green Heron - *Butprides striatus*	X	X
Anseriformes	Whistling Swan - *Olor columbians*	X	
	Canada Geese - *Branta canadensis*	X	X
	Mallard - *Anas platyrhynchos*	X	X
	Black Duck - *Anas rubripes*	X	
	Blue-winged Teal - *Anas discors*	X	X
	Gadwall - *Anas streperea*	X	
	Wood Duck - *Aix sponsa*	X	X
	Ring-necked Duck - *Aythya collaris*	X	
	Greater Scaup - *Aythya marila*	X	
	Bufflehead - *Bucephala albeola*	X	
	Ruddy Duck - *Oxyura jamaicensis*	X	
	Hooded Merganser - *Lophodytes cucullatus*	X	
Podicioedifornes	Pied-billed Greb - *Podilymbus podiceps*	X	
Falconiformes	Red-tailed Hawk - *Buteo jumaicensis*	X	
	American Kestrel - *Falco sparverius*	X	
	Northern Harrier - *Circus cyaneus**		X
Gruiformes	American Coot - *Fulica americana*	X	
	King Rail - *Rallus elegans**	X	
Charadriiformes	Herring Gull - *Larus argentatus*		X
	Killdeer - *Charadrius vociferus*	X	X
	Spotted Sandpiper - *Actitis macularis*	X	X
	Upland Plover - *Bartramia longacauda**	X	
	American Woodcock - *Philohela minor*	X	
	Willet - *Catoptrophorus semipalmatus*	X	
Columbiformes	Mourning Dove - *Lenaida macroura*	X	X
Coraciiformes	Belted Kingfisher - *Megaceryle alcyon*		X
Passeriformes	Red-winged Blackbird - *Agelaius phoeniceus*	X	X
	Eastern Meadowlark - *Sturnella magna*	X	
	Bobolink - *Dolichonyx oryzivorus**	X	
	Song Sparrow - *Meospiza melodia*	X	X
	Field Sparrow - *Spizella pusilla*	X	X
	Vesper Sparrow - *Pooecetes gramineus**	X	X
	Chipping Sparrow - *Spizella passerina*	X	X
	Common Grackle - *Quiscalus quiscula*	X	
	Barn Swallow - *Hirundo rustica*	X	X
	Tree Swallow - *Iridoprocne bicolor*	X	X

* Listed as species of special concern in Pennsylvania.

feeding on a regular basis by between 25-50 Canada geese and between 15-25 mallards, blue-winged teal, and wood ducks. During the past summer, six and four wood duck nesting boxes were placed on the Guarnieri and Edwards Mines, respectively, and six blue bird nesting boxes were placed on each mine.

In addition to birds, these areas were also used by several mammal species, including muskrat, mink, raccoon (*Procyon lotor*) and white-tailed deer (*Odocoileus virginianus*). On both the Guarnieri and Edwards Mines, wetlands provided additional ecological diversity to these sites and the excellent response of wildlife to these areas will enhance the overall ecology of the region. The response of the vegetation and the use of these areas by wildlife will be studied over the next several years to determine feasibility and economic benefits of wetland relocation and/or development to the overall ecology of the region.

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A PROGRAM TO MINE AND RESTORE A FORESTED WETLAND[1]

James R. Boyle, Jr.[2]

Abstract.--This paper describes the program initiated by the Bureau of Mines to mine a forested wetland. The program outlined details the step by step plans set up by the Bureau and implemented using cooperating federal agencies and a private company, and why these plans are used. A cost analysis is given.

INTRODUCTION

The mining of forested wetlands in the Central Florida phosphate region is hampered by the lack of data on restoration. Many of the studies for restoring wetlands disturbed by mining deal with freshwater marshes (U.S. Bureau of Land Management). Though valuable, these studies are not directly applicable to the restoration of forested wetlands. Due to this lack of information, the State's regulatory agencies very rarely permit the mining of forested wetlands because an acre of wetland reclaimed is required for every acre mined. To secure State approval and to gain data on forested wetlands, the Bureau of Mines developed a systematic program to mine and restore a small forested wetland. The Bureau coordinated the efforts of the United States Geological Survey (USGS), the United States Fish and Wildlife Service (USFWS), and the industry cooperator, AMAX Phosphates, Inc., (Mobile Chemical, Inc.). The combined efforts (fig. 1) resulted in the program described in this paper.

DESCRIPTION OF THE MINING PROGRAM

Test Site

The test site is part of the AMAX Big Four Phosphate Mine in Hillsborough County, FL (fig. 2). The site is approximately 16 acres and is part of a 92-acre tract of land designated by AMAX, Inc. as Mining Unit No. 1C (fig. 3). A small stream channel and its associated wetlands make up the test site. The stream channel is approximately 2,500 ft long with 1,000 ft being in the site. The flow in this stream is intermittent. During the dry season, baseflow is provided by ground-water seepage (Thompson, 1984).

Premining Monitoring

The monitoring plan is designed to gather enough data from the site to determine its natural condition and to develop a comprehensive revegetation plan. In conjunction, a control site is set up to define any hydrological or ecological changes that may occur in the area unrelated to mining. Monitoring includes the collection of ecological and hydrological data and the collection of soil and water samples for analysis.

The USGS implemented the following monitoring networks at the test and control sites.

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[1] Paper presented at 1988 Mine Drainage and Surface Mine Reclamation Conference sponsored by the American Society for Surface Mining and Reclamation and the U.S. Department of the Interior (Bureau of Mines and Office of Surface Mining Reclamation and Enforcement), April 17-22, 1988, Pittsburgh, PA.

[2] James R. Boyle, Jr. is a Mining Engineer, Bureau of Mines, U.S. Department of the Interior, Tuscaloosa Research Center, Tuscaloosa, AL.

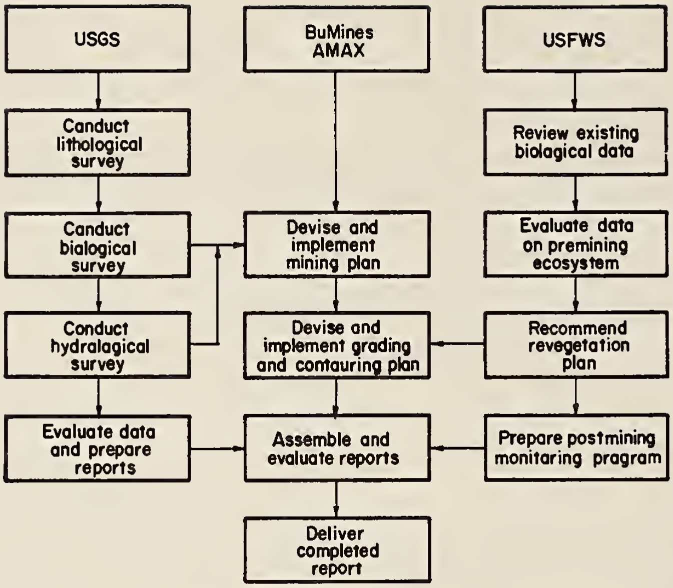
USGS
BuMines AMAX
USFWS
Conduct lithological survey
Review existing biological data
Conduct biological survey
Devise and implement mining plan
Evaluate data on premining ecosystem
Conduct hydrological survey
Devise and implement grading and contouring plan
Recommend revegetation plan
Evaluate data and prepare reports
Assemble and evaluate reports
Prepare postmining monitoring program
Deliver completed report

Figure 1. Diagram of Federal Agency and private cooperator responsibilities.

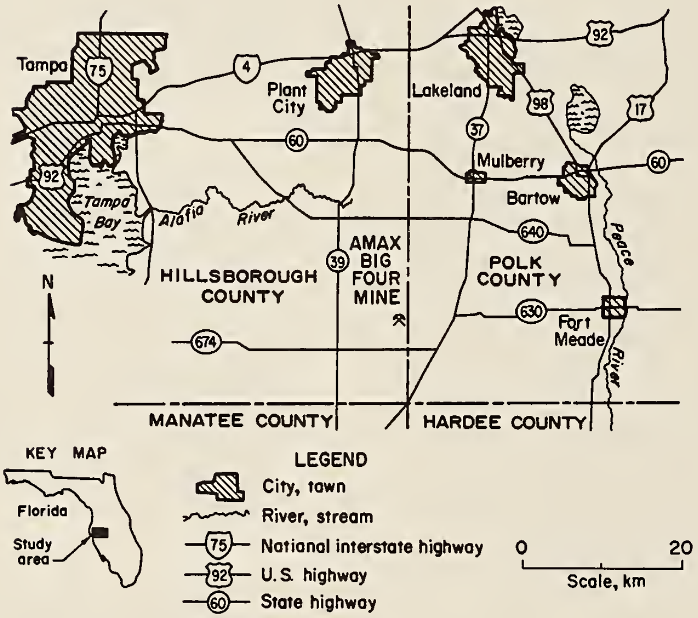
Tampa
75
4
Plant City
Lakeland
92
98
17
37
60
Mulberry
60
Bartow
92
Tampa Bay
Alafia River
640
Peace River
AMAX BIG FOUR MINE
39
HILLSBOROUGH COUNTY
POLK COUNTY
N
630
Fort Meade
674
MANATEE COUNTY
HARDEE COUNTY
KEY MAP
Florida
Study area
LEGEND
City, town
River, stream
National interstate highway
U.S. highway
State highway
0
20
Scale, km

Figure 2. Location of Big Four Mine in relation to the surrounding area.

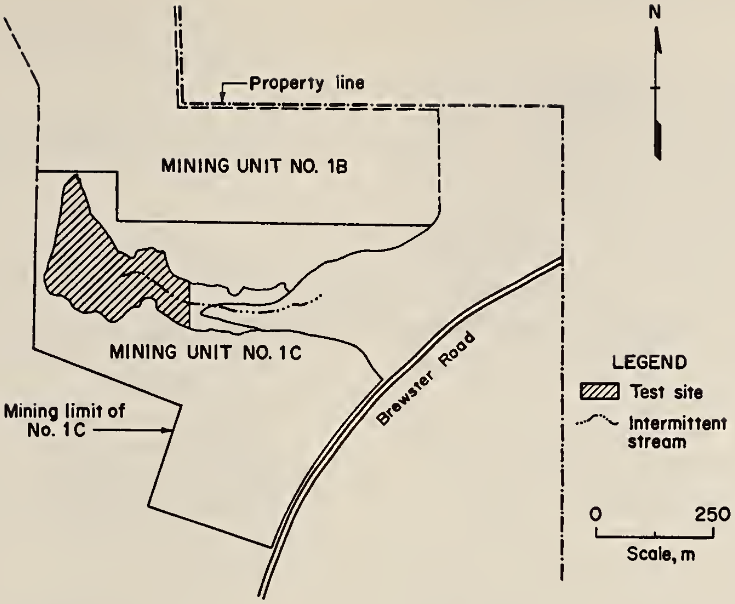
N
Property line
MINING UNIT NO. 1B
MINING UNIT NO. 1C
Mining limit of No. 1C
Brewster Road
LEGEND
▨ Test site
Intermittent stream
0 250
Scale, m

Figure 3. Mining unit No. 1C and portion covered by the test site.

Three test site linear transects (fig. 4) were established to observe the vegetative cover and gather benthic invertebrate samples. Transect A was in the test site, B was downstream in an area to be used as an unmined vegetation donor site, and C was to remain undisturbed. Information from the transects determined that the canopy and understory of the site was dominated by upland hardwoods (60 pct); the remainder of the system was freshwater swamp. Red maple, laurel oak, loblolly bay, water oak, sweet bay, red bay, swamp tupelo, wax myrtle and slash pine were identified as the dominant overstory species. Hydric indicators such as chain fern were dominant within 10 to 30 ft of the well incised creek. Flow was observed throughout monitoring. The system was almost homogenous along its entire length. The interior swamp was bordered on both sides by upland

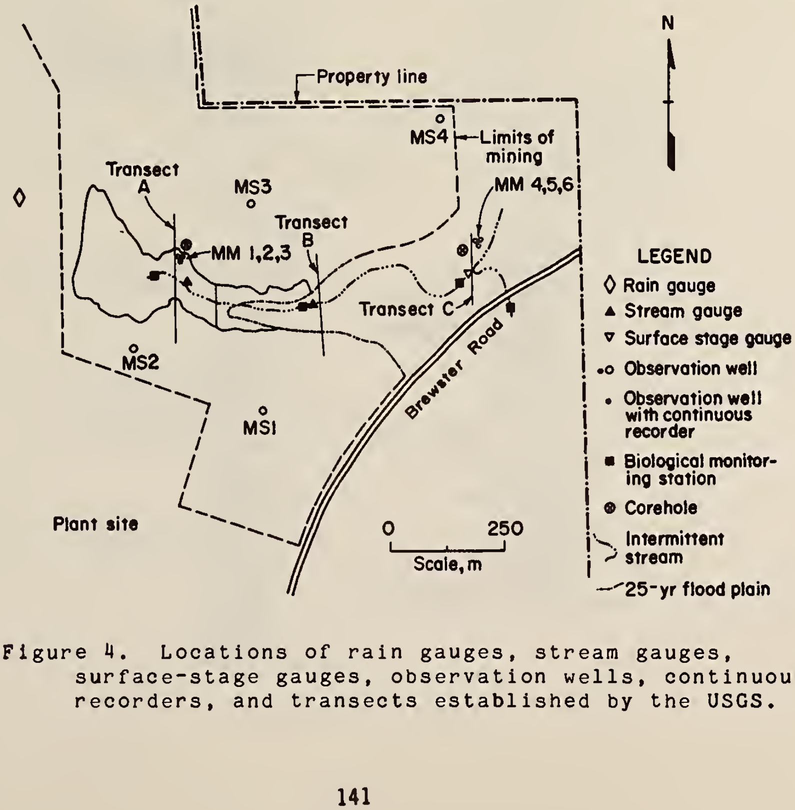
N
Property line
MS4
Limits of mining
Transect A
MS3
Transect B
MM 4,5,6
MM 1,2,3
Transect C
MS2
MS1
Brewster Road
Plant site
0 250
Scale, m
LEGEND
◊ Rain gauge
▲ Stream gauge
▽ Surface stage gauge
•o Observation well
• Observation well with continuous recorder
■ Biological monitoring station
⊗ Corehole
Intermittent stream
25-yr flood plain

Figure 4. Locations of rain gauges, stream gauges, surface-stage gauges, observation wells, continuous recorders, and transects established by the USGS.

hardwoods. Canopy and ground cover diversity was relatively high in this system.

Ground water was observed by using the series of observation wells shown in figure 4. The placement of these wells was used to determine ground water depth and seasonal variation. A stream gauge was used to determine baseflow of the stream. Surface and ground water samples were taken to determine premining water quality. Two core holes (fig. 5), one east and one west of the site were put down to determine the lithology. Soil samples were taken from each of the transects and were analyzed for nutrients.

The control site (fig. 6) was located approximately five miles southwest of the test site. The control and tests sites had approximately equal areas of hydric vegetation and hardwood forest. The control site had one linear transect and one biological monitoring station. The transect (AC) was run east-west to intersect the stream. The transect showed that the high ground was dominated by slash pine, saw palmetto, wax myrtle, and fetterbrush. Vegetation along the stream was palm oak hammock. The overstory was dominated by water oak, sweet bay, loblolly bay, and red maple. Ground cover was dominated by saw palmetto and chain fern (Thompson, 1984). The biological monitoring station was used for benthic invertebrate sampling.

Ground water was monitored by a system of wells similar to the test site. A stream gauge was used to determine baseflow.

The test site was monitored from October 1982 to September 1983. Monitoring at the control site continues.

Site Preparation

Certain procedures such as surveying and the stockpiling of topsoil are standard for restoration efforts. Surveying is used to determine the contour and to locate major topographical features of the site before it is disturbed. The stockpiling of topsoil is standard practice for most revegetation efforts. Other procedures, unique to a project, may have to be implemented. The Bureau and AMAX determined the procedures, standard and unique, used for the test site and they are described as follows:

Site preparation began with the surveying of the area to determine the contour and to spot the stream channel. An interceptor ditch was excavated and a dike constructed to protect the downstream area from runoff, since this area was not permitted for mining. Figure 7 shows the separation of the test site and the vegetation donor site. The donor site and the area downstream was not mined, but it will be used as a source for trees and other vegetation during transplanting.

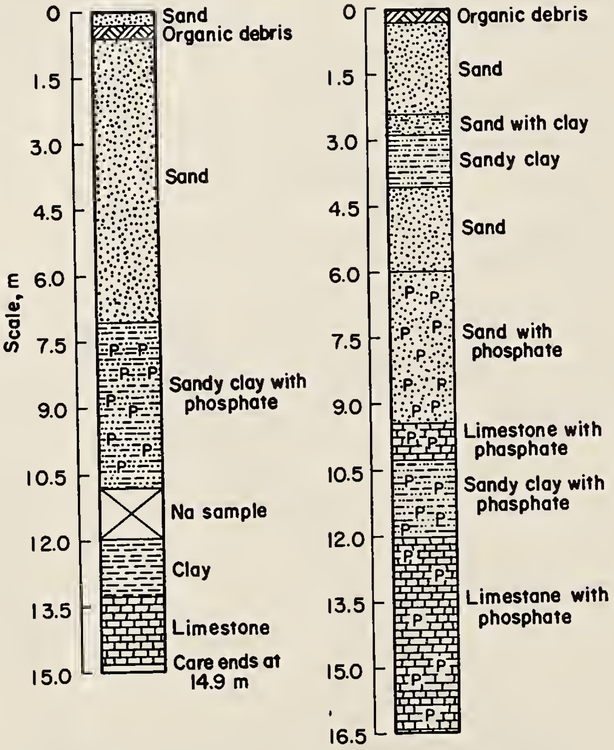
Scale, m
0
1.5
3.0
4.5
6.0
7.5
9.0
10.5
12.0
13.5
15.0
Sand
Organic debris
Sand
Sandy clay with phosphate
Na sample
Clay
Limestone
Care ends at 14.9 m
0
1.5
3.0
4.5
6.0
7.5
9.0
10.5
12.0
13.5
15.0
16.5
Organic debris
Sand
Sand with clay
Sandy clay
Sand
Sand with phosphate
Limestone with phosphate
Sandy clay with phosphate
Limestane with phosphate

Figure 5. Lithologic cores No. 1 and 2.

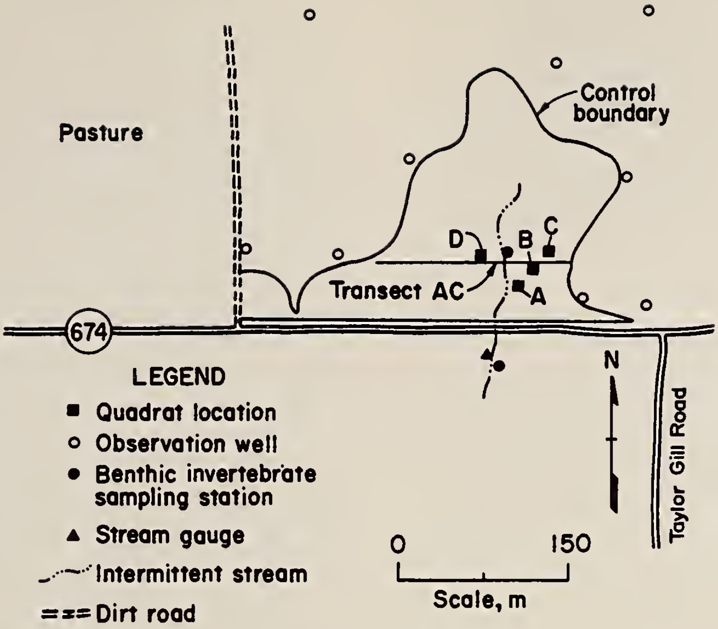
Pasture
Control boundary
D
B
C
Transect AC
A
674
N
Taylor Gill Road
LEGEND
■ Quadrat location
○ Observation well
● Benthic invertebrate sampling station
▲ Stream gauge
Intermittent stream
Dirt road
0
150
Scale, m

Figure 6. Network established by the USGS to monitor biological and hydrological conditions at the control site at Brewster's Ft. Lonesome Mine.

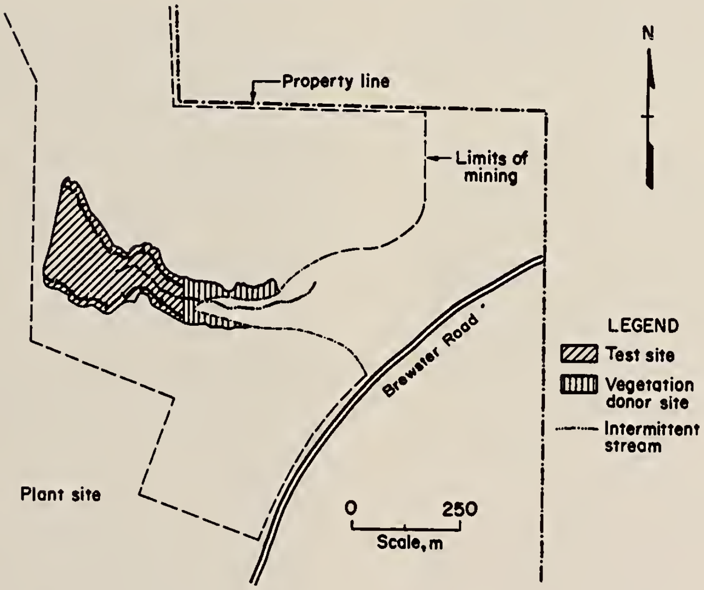
Property line
Limits of mining
N
Brewster Road
LEGEND
▨ Test site
▥ Vegetation donor site
Intermittent stream
Plant site
0
250
Scale, m

Figure 7. Test site and vegetation donor site.

The overstory was cleared by bulldozers, pushed into piles, and burned off. The topsoil was removed by pan scrapers and stockpiled within several hundred yards of the site. The stockpiles were graded and sloped for stabilization, but were not seeded because of the concern over establishing perennial plants that would be difficult to eliminate (Haynes and Crabill, 1984). Site preparation began in October 1983 and was completed in December of the same year.

Mining

This wetlands, as with most others, was part of a larger mining unit. The entire unit, including the wetlands, was mined using a 30-yd^3 dragline operating in east-west cuts. The overburden was windrowed, the ore matrix dumped into sluice boxes, slurried and pumped to the beneficiation plant. This is standard practice for the industry. Mining began in January 1984 and was completed in April of the same year.

Recontouring

The recontouring plan is used to place the site back to its original contour as closely as possible. Extra material normally must be brought in to replace the void left by the removal of the ore body. Other land features may need to be modified because of expedience or the inability to copy nature exactly. The following is the recontouring done at the test site.

Overburden was graded using the largest possible bulldozers available to limit compaction. Overburden from the mined upland area north of the site, was used to replace the matrix removed during mining, bringing the test site to rough grade. The upland area had sand tailings pumped between the windrows to make up for the volume lost. The final grade at the test site was placed using pan scrapers and bulldozers. The pan scrapers were used to haul and place the stored topsoil. Bulldozers were used to grade the actual contour. A sharp, meandering swale was placed for the original channel. This design will result in a channel nearly identical to the original, yet reduce the potential for erosion that would be caused by reconstructing the natural steep banks. Grading began in January 1985 and was completed in February 1986.

Revegetation

The revegetation plan developed by the USFWS is based on information gained from the premining monitoring. The plan includes anticipated maintenance activities, a method to evaluate the site after restoration, and postmining monitoring. The following is the plan outlined for this test site. The plan will be carried out by company personnel.

Vegetative islands will be taken from the downstream donor site (fig. 7) and transplanted along the meandering swale by a front-end loader. These "islands" are to consist of the topsoil and vegetation that will provide ground cover for the site. One or two larger trees, to provide ground cover shading, will be spaded with each island. Four to six islands per acre are planned to be placed. Handplanting of the community dominants, identified during the premining monitoring, will begin after the islands are in place. The community dominants are red maple, laurel oak, loblolly bay, water oak, sweet bay, red bay, swamp tupelo, wax myrtle, and slash pine. The seedlings and potted stock will vary in height and be planted at random to insure a staggered canopy.

Maintenance activities will consist of supplemental planting of tree seedlings, transplanting additional vegetative islands where natural species have not outcompeted invading weed species, mowing around small seedlings to enhance their survival, irrigation, and the use of herbicides. Irrigation will have to be used if the upland area has not been restored by the time planting begins.

Restoration of the project site will be evaluated based on the following criteria:

A. Tree species are viable and surviving with an average of 400 trees per acre and no acre has fewer than 200 trees. Short-term success will be determined after the first full growing season (Spring, 1989) as a survival average of 400 trees per acre. Long-term success will be determined after five full growing seasons (Spring, 1993) as tree cover exceeds 33 pct of the vegetative cover, and no acre has tree cover of less than 20 pct (Haynes and Crabill, 1984).

B. Herbaceous layer vegetation is naturally reproducing. In developing permit stipulations, the regulatory agencies involved recognized that it would be unreasonable to expect a postmining condition equal to or even nearly equal to the premining condition within a 5-yr evaluation period. However, if the restoration effort is truly successful, the postmining forest community and other related ecological factors will evolve toward the premining condition with the increasing age of the site (Haynes and Crabill, 1984).

Postmining monitoring will be conducted by the company. Plans call for the replacement of the observation wells and stream gauge used during premining monitoring. Survival rates of the planted stock will be taken. Samples from the streambed will be taken to determine biological activity and its progress.

RESULTS AND DISCUSSION

Cost

The cost of earthwork was approximately $1.50/m^3$ of material moved. Earthwork included all material moving activities such as removal and replacement of overburden, distribution and rough grading of overburden, and the final contouring with stockpiled topsoil.

Estimated revegetation costs include seeding and overstory planting. Seeding with mulching for erosion control costs $525 to $600 per acre. Costs for overstory planting will vary with the type planted. Bareroot seedling cost is $14 to $30 per thousand plus $0.30 per tree for planting. Potted stock cost is between $3.50 and $20, depending on size, plus an additional $1 per tree for planting. The cost for tree spading is approximately $25 per tree. An estimated 6,000 to 7,000 trees will need to be planted.

The following are costs per acre. Monitoring represents premining and postmining combined.

Earthwork	$5,700
Revegetation	$2,000
Monitoring	$3,600

CONCLUSIONS

The most important part of the program is the premining monitoring plan. In a system as complicated as a forested wetland, the premining monitoring plan gives the essential information needed to develop the revegetation plan. It is very doubtful that a forested wetland in Central Florida could be permitted to be mined without some sort of premine monitoring. The implementation of the revegetation plan is next in importance. Close supervision of this area is needed to insure a successful completion to the program. Site preparation, mining, and recontouring, although important, are handled by mine personnel every day and are for the most part routine.

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WETLANDS REHABILITATION FOLLOWING MINERAL SANDS MINING IN AUSTRALIA[1]

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Abstract.--The mineral sands industry has rehabilitated a variety of native ecosystems, including wetlands, on both the east and west coasts of Australia. On North Stradbroke Island in southern Queensland, wetland habitats have developed by natural succession in depressions formed within the frontal dune system. Rehabilitation was facilitated by planting a rhizomatous sedge as a primary colonizer. Subsequent vegetation distributions were closely related to soil water availability. On an extensive wet heath plain in northern New South Wales, techniques were developed to rehabilitate a range of wetlands ecosystems. It was essential to reestablish ground levels accurately and to drain surface water before and after mining. Topsoil techniques were developed to aid regeneration from vegetative propagules. The vegetation also responded to moderate fertilizer dressings. The site is now incorporated in a national park. At Capel in Western Australia, a series of lakes formed from volume loss during mining are being developed as wetlands for waterbirds. Baseline studies have identified the current limitations of the young habitats whilst highlighting their potential for further development. A five-year programme has commenced involving site development works and an integrated research programme on wetlands development and waterbird ecology, with particular emphasis on the food chain.

INTRODUCTION

Mining for the heavy mineral sands rutile, zircon, ilmenite and monazite commenced at Byron Bay on the north coast of New South Wales, Australia, in 1934 (Morley 1981). Two factors enabled the industry to develop to the extent that Australia has dominated world markets for these products. First, certain geological processes placed deposits with the world's richest grades of rutile and zircon in coastal sand masses on Australia's east coast (Shepherd 1986). These rich ore bodies were formed in coastal dunes extending from north of Sydney in New South Wales to Rockhampton in Queensland (fig. 1). In Western Australia, major deposts were also formed on the coastal plain both south and north of Perth, although these deposits were more varied in their mineral assemblage. Second, the technology for the efficient mining and separation of the

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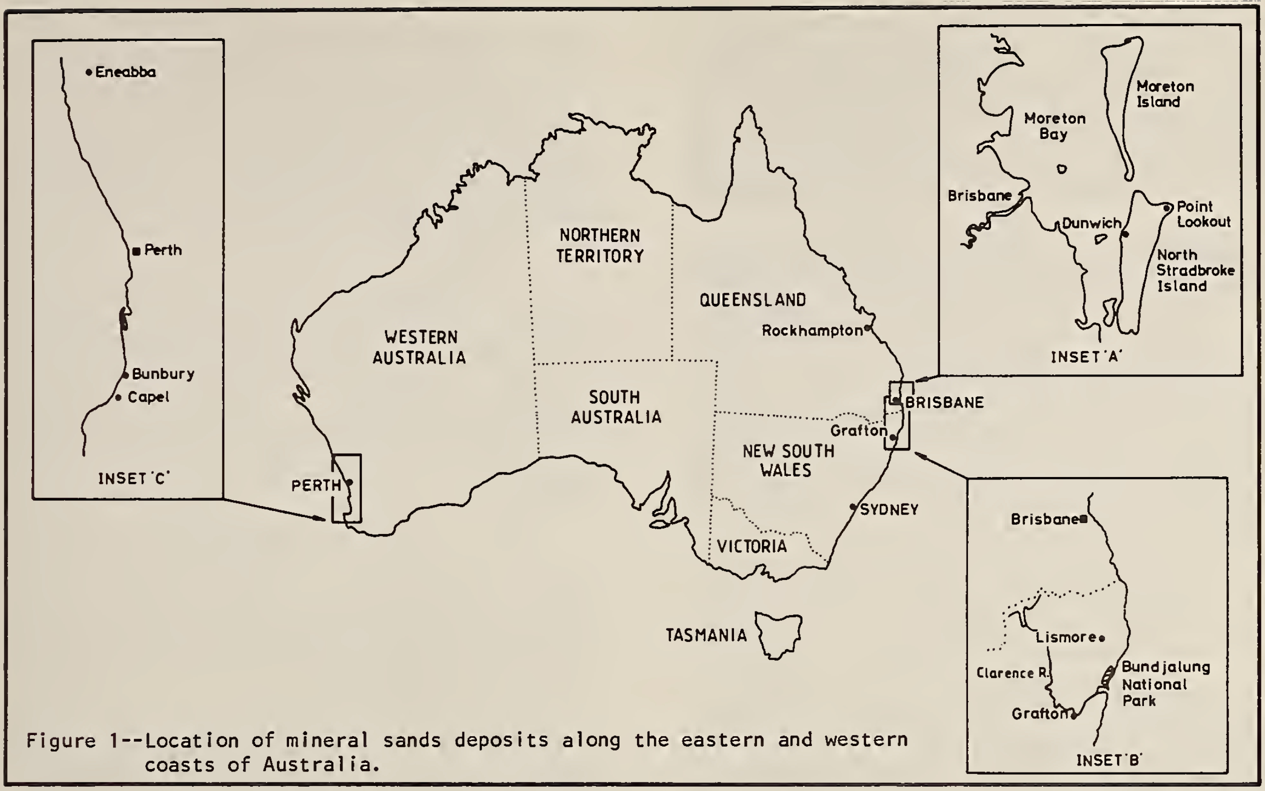
Eneabba
Perth
Bunbury
Capel
INSET 'C'
PERTH
WESTERN AUSTRALIA
NORTHERN TERRITORY
SOUTH AUSTRALIA
QUEENSLAND
Rockhampton
BRISBANE
Grafton
NEW SOUTH WALES
SYDNEY
VICTORIA
TASMANIA
Moreton Bay
Moreton Island
Brisbane
Dunwich
Point Lookout
North Stradbroke Island
INSET 'A'
Brisbane
Lismore
Clarence R.
Bundjalung National Park
Grafton
INSET 'B'

Figure 1--Location of mineral sands deposits along the eastern and western coasts of Australia.

heavy minerals was developed in Australia (Morley 1981). As a consequence of its development, Australia's mineral sands industry has mined over many landforms, vegetation types, and climates, and developed its technology for rehabilitation of native ecosystems accordingly (Brooks 1987).

On the east coast, the major landforms mined were frontal dunes of Holocene age, coastal lowlands containing strand lines of late Pleistocene age, and aeolian high dunes ranging in age from Holocene to Pleistocene. Vegetation types included sand spinifex grasslands of the frontal dunes, closed scrubs, sclerophyll forests, heaths, wetlands, and littoral rainforests. The climate varies from temperate in the south to subtropical in the north, with annual average rainfall in the range of 1,100-1,600mm (43-63 inches).

On the west coast, the landform consists of extensive sand plains with subdued topography, possibly of late Tertiary or Pleistocene age. Considerable mining has taken place on agricultural land, particularly in the southwest, although some low quality forests have also been encountered. In the Eneabba area, north of Perth, low complex heathlands cover much of the mineralized areas. The climate is Mediterranean, with rainfall varying from about 530mm (21 inches) in the north to 830mm (33 inches) in the south.

In this paper, the author will discuss rehabilitation of wetlands carried out by Associated Minerals Consolidated Limited (AMC), the world's largest mineral sands producer, in three states of Australia.

NORTH STRADBROKE ISLAND

North Stradbroke Island is a large sand mass lying 40km (25 miles) offshore from Brisbane in southeast Queensland (fig. 1). Together with Moreton Island immediately to its north, it encompasses Moreton Bay. The island has an area of 27,520ha (68,000 acres) and is approximately 37km (23 miles) long and 11km (7 miles) across its widest point.

The climate of North Stradbroke Island is subtropical. Mean maximum temperatures range from 19.4°C in July to 28.0°C in January, whilst mean minimum temperatures range from 11.5°C in July to 19.9°C in January. The mean annual rainfall is 1,645mm (65 inches), with the heaviest falls occurring in the January-March period.

Whilst aeolian high dunes of Pleistocene and Recent times occupy the bulk of the island, frontal dunes formed in the Holocene extend the full length of the island's east coast. Behind the frontal dunes and at the foot of the high dunes lies an extensive freshwater swamp (Eighteen Mile Swamp) at about R.L. 4.5m, which is a window of the hydrological gradient from the high dunes to the sea. The frontal dunes have experienced long periods of instability. Wartime aerial photography indicates numerous large blowouts, both active and inactive, encroaching into the swamp behind (Brooks 1980). Indeed, the northern part of the swamp had been overrun by sand drift from the unstable dunes. Prior to mining, the frontal dunes were mostly bare drifting sand with only a few remnant vegetated dunes occurring just above high water mark.

Mining for mineral sands commenced about 1950 as a scraping operation centred on high grade beach placers (Morley 1981). In 1956, small-scale dredging commenced on the frontal dunes, with operations concentrated on the northern half of the dune system. In 1970, the Company moved a large dredge and concentrator unit onto the southern end of the frontal dune system. From there, the plant moved northwards along the dunes, through both virgin and previously mined ground, and mining was completed in this system in 1977.

Rehabilitation of these frontal dunes after mining aimed at recreating a diverse, though stable, landscape so as to allow a number of plant communities to develop in the various habitats formed (Brooks and Bell 1984). The dunes were revegetated with sand spinifex grass (Spinifex sericeus) and other herbs, together with native tree and shrub species adapted to this habitat.

With the methods used, a number of depressions were formed in the dune system, some deliberately, some by natural means. Many of them intersected the ground water table, and wetlands vegetation began to colonize them. It soon became apparent that successional development of new ecosystems was occurring, and this attracted the interest of research students of Queensland Institute of Technology and the University of Queensland.

The main depression studied dates back to 1974, when it was a deflation zone behind a broken line of remnant dunes. The mining plant passed by on the western side during January, 1974, whilst high winds and heavy rains associated with cyclonic conditions prevailed in the area. Heavy seas washed into the depression at that time. Later in the year, the remnant dune was repaired with levees across the washouts, dune-building fences, and fertilizer to encourage the growth of spinifex. The adjacent mined area was rehabilitated in the usual way (Brooks 1980).

Initially, the water trapped in the depression was saline, but as the ground level was below the natural ground water gradient, the salt water was quickly flushed out. In September, 1974, shoots of the small rhizomatous sedge Carex pumila were planted around the banks of the resulting waterhole to provide stability. Within three months, the Carex pumila had formed a complete ground cover, there were algae and invertebrates in the pond, and birdlife was attracted to the area.

By February 1975 a total of 12 native plant species had colonized the pond and its immediate environs, although only one of these (Carex pumila) had been planted. In May of that year, seedlings of Banksia integrifolia, Casuarina equisetifolia, Cupaniopsis anacardioides, and Pandanus pedunculatus were planted around the banks as part of the tree planting programme for the surrounding area.

In November 1977, studies of various aspects of the developing ecosystem were initiated. In February 1978, the depression was approximately 40m wide, and the pond 140m long, up to 30m wide and 1.25m deep. At this stage movement of sand into the depression from the beach had been halted by spinifex on the rehabilitated foredune.

In May 1978, 40 species were recorded for the site not including the tree seedlings planted in 1975 (College 1978). In August 1979, the count was 43 including 7 which were not recorded in 1978, while 4 species recorded in 1978 appeared to have died out (Connell 1979).

All of the species which colonized the site had seed or other propagules which would allow either wind or bird dispersal. As the prevailing wind was from the sea, it would appear that birds and perhaps other animals were the prime source of propagules in the area.

More than half of the species recorded in 1979 were common with a group of similar undisturbed "seepage areas" on Moreton Island to the North (Durrington 1977). Observations on other similar ponds on Stradbroke Island indicate that, with age, such sites become more similar to undisturbed sites when considered on the basis of species composition (Connell 1979).

The very rapid increase in both standing biomass, particularly in Typha and Scirpus communities, and the accumulation of organic matter in and around the pond has provided food and protection for a variety of fauna including birds, reptiles, mammals, amphibians, and invertebrates. Fish occur in the pond, but their origin is uncertain.

In an attempt to define those factors determining the distribution of the major plant species around the pond it became apparent that the distributions were closely related to the level of available soil water. As might be expected in such well-drained sands, total standing biomass was correlated with water availability, and generally decreased with vertical distance from the pond.

It would appear that the choice of C. pumila for early planting around the pond was a good one. Although it originally formed quite thick pure stands, it has given way to many other native species, particularly Phyla nodiflora and Bacopa monniera. Toward the end of 1978 about equal biomass contributions were made by these three species, but C. pumila spanned a wider range of environmental conditions (including soil water and nutrient availability) than the other two, or indeed any species present (College 1978). Although the pond was entirely surrounded by S. sericeus, virtually none of it has grown into the pond or its margins. This suggests that planting of species such as C. pumila can be valuable in stabilizing and revegetating wet depressions. The presence of readily available water is the greatest difference between such a depression and its surrounding dunes. The resulting plant community apparently progressed very much further along its successional path than its surroundings, and in so doing provided a significant degree of shelter for further plant and animal "colonizers".

Following the promising early development of the vegetation in this depression, a similar approach was adopted at other sites in the dune system. In particular, a number of lagoons had been created during and at the completion of mining, and their banks were planted with C. pumila in the same way. Similar successional development occurred, although it appears that their rate of development may have been influenced by such factors as site exposure and water depth.

It was concluded that the techniques employed enabled habitat diversity to be increased in the newly stabilized dune system. Success resulted from creating suitable conditions for plant colonization to follow natural successional trends.

JERUSALEM CREEK

Many mineral sands ore bodies on the east coast occur as ancient strand lines underlying extensive heath plains referred to as coastal lowlands. The topography of these lowlands is subdued with complex drainage patterns giving rise to a mosaic of dryland and wetland vegetation associations. Typical vegetation types include low dry open forests and shrublands, dry heaths, wet heaths, sedgelands, and swamp woodlands.

One such area occurs on the north coast of New South Wales at a location known as Jerusalem Creek, north of the Clarence River (fig. 1). Mining commenced here in 1890, when prospectors discovered gold in the ancient strand lines, and small-scale gold mining continued spasmodically for many years (Morley 1981). Following World War II, a number of small mineral sands operations were carried out, however, they failed to survive various market pressures. Subsequently, AMC commenced large-scale operations in 1969, and continued through to 1982 when it was forced to close by government restrictions. Mining was conducted by bucketwheel excavator followed by a concentrator unit floating in a pond created by levees built across the pit. The mining plant followed the strand lines on a series of narrow, more or less parallel, mine paths over an area of about 13km^2 (5 mi^2).

For the first four years, the mining plant followed a low sand ridge supporting dry heath vegetation. Rehabilitation of this landform followed principles developed elsewhere (Brooks 1987). In 1974, the mining plant moved onto the lower lying country supporting wetlands vegetation associations. On this landform, the water table was typically at or above the ground surface for 4-6 months of the year, falling below ground level during the drier late winter-early spring months. The vegetation type was governed by moisture relationships, with wet heaths being slightly higher and inundated for shorter periods than sedgelands. Swamp woodlands carried surface water at all times except droughts.

Techniques for rehabilitating these wetlands were developed from hard experience. Early attempts were thwarted by a series of flood events. Vegetation attempted to regenerate from rootstock and seed in the replaced topsoil a number of times. On each occasion, the young vegetation was killed by scalding from the shallow surface water following heavy rains. Finally, about two years after the initial topsoil return, a short-term drought allowed the water table to fall below the surface and enabled freshly regenerated vegetation to develop above the height of normal water levels. The vegetation has since continued to develop satisfactorily.

From this experience, three important interrelated principles for the rehabilitation of wetlands were developed. Subsequent experience proved they were equally applicable to all wetlands vegetation types encountered.

First, it is essential to reestablish ground levels accurately. In this type of country, variations in contour are subtle, and changes in ground level of as little as 15cm (6 inches) can have a profound effect on drainage patterns and, hence, vegetation recovery. Therefore, control of tailings placement by operations personnel is critical and needs to be carefully planned.

Second, drainage of the area before and after mining is essential. Small drains were installed prior to mining to remove surface water, enabling the topsoil to be removed in moist though not sloppy condition. Otherwise, saturated topsoil would cause a loss of viability of propagules following disturbance. After mining the drains were reinstated so as to keep the water levels at or below the ground surface whilst the vegetation reestablished. The drains were removed when the vegetation had gained sufficient height and maturity to cope with inundation.

Third, topsoil handling procedures are critical because a high proportion of this vegetation can recover from vegetative propagules in the soil. Not only is moisture content important, but the topsoil needs to be handled carefully by the bulldozer operators. At Jerusalem Creek, a double stripping method was developed in order to minimise disturbance to the soil and damage to the plant propagules. The top 20-25cm was removed in slices by the bulldozer so as to retain the soil and plants in large lumps, and stored to one side of the mine path. A further 10-15cm was then stripped and stored on the opposite side. Immediately after the mining plant had returned the tailings to the mine path, the topsoil layers were returned to their respective positions. The topsoil storage time was governed by the rate of forward progress of the mining plant, but was of the order of 1-3 months.

Regeneration of the vegetation was further enhanced by the application of a moderate dose of mixed fertilizer following topsoil return. In an experiment conducted in 1976, a mixed fertilizer (10.0N:3.9P:6.1K) was applied to large plots (50m by 100m) at the rate of 500kg/ha (4 cwt./acre). At age 16 months, the regenerating wet heath had a higher species number, percent cover and abundance with fertilizer compared with no fertilizer (table 1). In fact, the area with fertilizer treatment had a higher species number than before mining, even though the soil had been retained within the boundaries of the vegetation association. The topsoil disturbance had stimulated species lying dormant in the soil. These species were usually relatively short-lived.

A common feature of the heath vegetation on the sand plains of the eastern Australian coastline is the widespread distribution of *Xanthorrhoea* spp. At Jerusalem Creek, *X. resinosa* subsp. *fulva* is a dominant or subdominant species, with cover values ranging from 6% to 28%, and densities from 5 to more than 10 "crowns"/m^2 (up to 105,000/ha). In the wet heath habitat, this species adopts an acauline habit, and many plants are multi-crowned. They rarely flower except after fire, and it is probable that the species is part of a fire-induced climax and an important component of the vegetation.

Whilst it is generally believed that the species will not survive topsoil storage, it was observed that at least some of the original plants survived the handling procedures used. Topsoil storage time and stripping method were two potential factors. To quantify these effects plant counts were carried out at five sites within the same plant community. All live crowns were counted at each site in 10 quadrats, each 10m by 10m, laid out in a line transect.

Table 1.--Response of rehabilitated wet heath at Jerusalem Creek to fertilizer at age 16 months (Brooks unpublished data).

	FERTILIZER	
	-	+
SPECIES NUMBER	25	39
PERCENT COVER	1.2	34.9
ABUNDANCE	1.15	5.27
SPECIES NUMBER PRE-MINING	34	

When topsoil was single stripped, there was no positive response to reduction of storage time on survival and regeneration within the time scale measured (table 2). However, at age 2 years, there was a large response to double stripping compared with single stripping. This response was further illustrated by the high level of regeneration at the site of age 1 year, after topsoil handling procedures had been further refined. Although the percentage survival of the plants is low, the level of regeneration is high relative to alternative methods available. As opportunities to collect seed of this species were very rare, it was not possible to reestablish it by direct seeding. Even if sufficient seed was available to raise nursery stock, it would not be economically feasible to plant out such stock at the densities shown. Hence, the additional care required in topsoil handling for the level of regeneration achieved was fully justified.

During the study it was also observed that the disturbance encouraged the plants to flower subsequently. This occurred at about age 3 years, when 20-30% of the plants were recorded in flower. Thus, although the population of *X. resinosa* subsp. *fulva* was reduced, significant numbers of plants survived with the potential to increase the population further in future years.

The adoption of the rehabilitation techniques described enabled the various vegetation associations, including swamp woodlands, to recover rapidly and successfully. The mined area is now incorporated in the Bundjalung National Park, and listed on the Register of the National Estate. In considering the registration, the Australian Heritage Commission formally acknowledged the success demonstrated in reestablishing the native ecosystems.

Table 2.--Recovery of crowns of Xanthorrhoea resinosa subsp. fulva from different topsoil handling regimes at Jerusalem Creek (Brooks unpublished data).

	SITE 1	2	3	4	5
Density (crowns per hectare)	430	670	110	1,970	6,540
Age (year)	3	3	2	2	1
Topsoil Storage Time (month)	1-2	3	1-2	1	1-2
Stripping Method	Single	Single	Single	Double	Double

CAPEL

In Western Australia, continuous mining for mineral sands commenced near Capel, 200km (125 miles) south of Perth, in 1956 (Baxter 1977). Mining in this area was based on the lower value mineral ilmenite, although very high grades have been mined at some sites resulting in significant volume loss. Whilst the contours of surrounding areas have been restored, the volume loss has been accounted for by creating lakes where the pits have intersected the water table.

Because more than three-quarters of the wetlands on the Swan Coastal Plain have been destroyed through various forms of development, these newly created lakes are showing potential for development as valuable waterbird habitats. Permanent freshwater bodies are particularly scarce, as in this Mediterranean climate (AAR 830mm, 32.5 inches) many wetlands dry up during the summer months.

The Company's minesite just south of Capel contains a series of such lakes. The main lake system was formed during mining between 1975 and 1979. There are eight lakes in the system with a total water surface of about 56ha (140 acres). Most of them are interconnected, as they receive effluent from the mineral processing plants and serve as the mine water supply. Some of the lakes occur on private land, although the majority of them are in a State Forest.

Initially, rehabilitation of the area mined was concentrated on reestablishing pastures on the surrounding land and on planting trees and shrubs around the banks of the lakes for aesthetics and to attract birdlife. Most of this work took place between 1977 and 1983. Meanwhile, the lakes became partially colonized with wetlands flora, and waterbirds were frequently observed to visit them.

In 1984, the Company commissioned the Royal Australasian Ornithologist's Union (RAOU) to advise on the potential of the lakes for development of self-sustaining wetlands ecosystems for the benefit of waterbird conservation.

Jaensch (1985) reported that, with a number of development techniques, the lakes had considerable potential to achieve the stated objective, as well as providing considerable opportunities for research, education and passive public recreation. On this basis the Company initiated its Wetlands Project in 1986.

A management committee for the project was established to advise the Company on objectives and priorities, management and research proposals, and budgets, and to review progress. Through its membership the committee taps the main expertise and responsibilities for wetlands and waterbird conservation in the state, thereby forging links with appropriate Government authorities, and research and conservation institutions. There is representation from the Company, RAOU, Department of Conservation and Land Management, University of Western Australia, and Curtin University of Technology.

One of the first steps in the project was to initiate a series of multi-disciplinary baseline studies to determine the current ecological status of the lakes and to indicate priorities for future research and development. Nearby natural wetlands were used as control sites. These studies were completed during 1987 and planning for a habitat enhancement programme and an ongoing research programme was commenced.

A preliminary survey of waterbird usage of the lakes, using volunteer observers once a month, was conducted from November 1984 to November 1986. A total of 24 species of waterbirds was recorded on the lakes system during the survey period (Jaensch 1986, Bamford and Jaensch 1987). Whilst the lake system supports an appreciable number of species and individuals, it is not as valuable as other natural wetlands in the district. Limitations of the habitat in supplying food and shelter were reported as being the main probable factors. This conclusion was supported by the observation that the older lakes were more heavily utilized by the waterbirds. Seasonal patterns of usage revealed that the system was of greatest value as a refuge in the dry season (late spring to late autumn) when seasonal waterbodies in the district dried up. Two species, Pacific Black Duck and Black-fronted Plover, were observed breeding on the lakes during the survey.

The breeding success of waterbirds on the lakes was studied during the 1986/87 breeding season (Bamford 1987). Although 12 species bred on a nearby natural swamp, 5 species bred on the lake system with a poor success rate. Most losses occurred within the first two weeks from hatching, the major causes apparently being poor nutrition and predation. The Pacific Black Duck, which relies heavily on invertebrates as a protein source, fledged only 2 ducklings from a minimum of 22. On the other hand, the Purple Swamphen, which has a more varied diet, fledged 7 chicks out of a minimum of 10. Breeding success was highest on the oldest lakes with better developed emergent vegetation providing more breeding sites and improved nutrition. The species list was increased to 27 during this study, 25 of which could have bred on the lakes given suitable conditions. Thus, these results reflect the early development of habitats on the lake system.

Lack of invertebrate larvae as a protein source was confirmed as one of the major factors in the poor breeding success of the birds (Cale and Edward 1987). Whilst the lakes have a high invertebrate species richness, abundance is low compared with natural wetlands. Eighty-three invertebrate taxa were recorded, the most abundant being Coleoptera (18%), Chironomidae (17%) and Crustacea (10%). The oldest lake supported 57% of all identified taxa, and was best in all habitat components, i.e., benthic, macrophyte and plankton. This result correlates strongly with the level of macrophyte cover. The faunal studies confirm that the lakes have the potential for development as self-sustaining wetlands, although the need to increase their productivity through habitat development is highlighted.

Factors limiting the productivity of the lakes were found by Gordon and Chambers (1987) to include steep slopes, hard substrates, and poor water quality. The ponds are well oxygenated, have no temperature and oxygen stratification, and show small diurnal changes. Water quality limitations include low pH, extremely high ammonia levels, low phosphorus concentrations, and high iron and manganese levels which could give rise to phosphorus complexing. Sediments are also low in inorganic and organic phosphorus. These studies demonstrate the need for extensive landscaping of the existing system to provide shallow areas with wide flat banks of soft sandy substrate so as to encourage the development of vegetation. Water quality is improving as effluent treatment facilities of the processing plants are being upgraded.

Hydrology studies have revealed that water levels in the lakes are being maintained artificially high by 0.5-1.0m because of the effluent stream and management of the lake system for mine water supply (Nield and Townley 1987). It was concluded that water levels would fall back to the natural surficial aquifer level when operations ceased in the long term. However, as a water bore is now being installed to supply the mine with make-up water, water levels in the lake system will be adjusted to reflect natural ground water levels.

With the benefit of these studies, a long-term conceptual plan has been developed for the lakes. It is planned to create a variety of habitat types to provide refuge for a large range of waterbird species on these permanent freshwater bodies. The plans also involve the development of education and passive recreation facilities in keeping with a multiple-use concept for this zone of the State Forest integrating conservation, recreation, and education with nearby forestry. A visitor's centre is planned with parking and picnic facilities. A number of walking trails will be developed incorporating a series of hides and viewing towers at strategic locations.

Site development works have commmenced during the 1987/88 summer to enhance the limited habitat range by providing feeding, breeding, and loafing sites for the birds. The work programme includes earthworks to create channels, moats and islands, landscaping of banks, mass plantings of wetlands trees, shrubs and emergent vegetation, construction of wave barriers and artificial floating islands, and installation of nestboxes. These works will continue over a five-year programme.

An ongoing research programme will be an integral component of the project. The programme will integrate studies of wetlands development and waterbird ecology, with particular emphasis on the food chain. There will be studies on sediment/water/nutrient interactions, vegetation and invertebrate recolonization, bird diets, breeding patterns, and the pattern of usage of the developing ecosystem by birds. The project will have obvious benefits in wetlands conservation, particularly in view of the dramatic loss of natural wetlands in southwest Western Australia. The multidisciplinary nature of the research programme, integrated by the Management Committee, is attracting considerable interest in the scientific fraternity. The project will increase understanding of wetlands, and will also help to develop and demonstrate the technology for the rehabilitation of wetlands. It is believed that the project is unique in Australia.

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THE ENVIRONMENTAL SIGNIFICANCE OF TOXIC METALS FOUND IN FISH COLLECTED THROUGHOUT THE COALFIELDS OF PENNSYLVANIA[1]

JOHN A. ARWAY[2]

Abstract. Fish were collected from seven streams located within the Pennsylvania bituminous coal region to determine whether levels of toxic metals which were presently exempt from regulation could be accumulating in fish and posing a potential threat to the environment and its users. Station locations were chosen based on a review of historical information and were sampled directly downstream of National Pollutant Discharge Elimination Systems (NPDES) permitted discharge points from various active mining and processing facilities. Fish were collected by electrofishing and attempts were made to collect both adult predator species as well as bottom feeders. Whenever gamefish were included in a sample, both fillets and whole fish were submitted for analysis. Samples were analyzed for 14 selected metals based upon their suspected occurrence and 26 organochlorine pesticides and polychlorinated biphenyls (PCBs). Sampling was conducted as part of the U.S. Fish and Wildlife Service's (FWS) Environmental Contaminants Program and results for seven elements (As, Cd, Cu, Hg, Pb, Se and Zn) were compared to national background levels from a database of 112 monitoring stations described in the U.S. FWS's National Contaminant Biomonitoring Program (NCBP). Concentrations meeting or exceeding the 85th percentile for cadmium, copper, mercury and selenium were recorded for five of the seven sites sampled. Data for eleven priority pollutants listed by the Environmental Protection Agency were also compared to human health criteria for protection against consuming contaminated fish tissue. However, sufficient populations of gamefish were not sampled at any site exceeding 85th percentile concentrations to illicit public health concerns. Comparing data

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on copper and iron for organoleptic effects (avoiding consumption because of poor taste or odor), brook trout and rock bass whole specimen samples for two different sites exceeded the recommended 1 mg/L copper level and edible portions of gamefish from four sites exceeded the 1 to 2 mg/L iron level. The analytical results from the pesticide and PCB testing did not indicate any unusual problems. Samples from large developed watersheds showed signs of chlordane, DDT, dieldrin and their derivatives. Since this study was an initial screening of a small subsample of NPDES permitted minesite discharges and did reveal a potential environmental problem, future monitoring, provided available funding, will be attempted upstream and downstream of certain locations. This effort should verify the actual origin of the contaminants or document whether the problem is from another source further upstream.

INTRODUCTION

Toxic pollutant control became a national issue in 1976 when the Natural Resources Defense Council, Inc. sued the U.S. Environmental Protection Agency (EPA) for failure to control toxic pollutants as required by Section 307(a) of the 1972 Federal Water Pollution Control Act Amendments. A settlement agreement was executed and EPA susbequently established a list of 65 classes of toxic chemicals encompassing 129 compounds (priority pollutants). The court settlement also caused the Clean Water Act of 1977 to be signed into law with a major emphasis on toxic pollution control. Since publication of the original priority pollutant list, EPA has been compiling the most up-to-date scientific information on selected toxic compounds which are suspected of being a threat to public health or the environment. EPA periodically releases this information in the form of ambient water quality criteria. A summary of 64 aquatic-based and human health-based criteria documents was published in 1980 (U.S. EPA 1980). The most recent EPA criteria document, the "Gold Book", was released as a subscription service which automatically updates the user as new criteria documents become available (U.S. EPA 1986).

The 1976 settlement agreement also required EPA to develop Best Available Technology Economically Achievable (BAT) effluent limitation guidelines, pretreatment standards, and new source performance standards for the 65 priority pollutants and classes of pollutants for 21 major industries. The coal industry was included in this group since relatively little was known about toxic pollutants as constituents of coal mining-related wastewaters. EPA conducted a comprehensive study to determine the status of toxic pollutants in coal mining wastewaters. This study involved identification of raw waste and treated effluent characteristics, including: 1) the sources and volume of water used, the processes applied, and the sources of pollutants in the plant; and 2) the constituents of the wastewaters, including 129 toxic pollutants, of which 13 were toxic metals (U.S. EPA 1981). EPA concluded that the levels of toxic metals at both surface and deep mines were so low that the best practicable control technology currently available (BPT), as required by the 1972 Water Pollution Control Act for conventional pollutants, was sufficient to control the discharge of toxic pollutants from minesites. Their conclusion was based on four factors: 1) toxic metals were only found at or very near detection limits; 2) toxic metal reduction levels were insignificant beyond BPT levels; 3) BAT levels required by the 1972 Act were infeasible because of technical and cost considerations; and 4) toxic organics while sometimes found were observed at levels too low to effectively treat (U.S. EPA 1981). The study most importantly recognized that toxic metals may occasionally be present in high concentrations because of site-specific conditions. It was recognized that when high concentrations occurred, permit writers would have the authority to establish particular limitations (U.S. EPA 1981). Final rules exempting mining-related point source discharges from toxic's control were published in the Federal Register in October, 1985 (D. Sweeney, Personal Communication, 1987).

Pennsylvania's coal mine regulatory program is administered by the Department of Environmental Resources (DER) through the Bureau of Mining and Reclamation (BMR). The Commonwealth gained primacy for its regulatory program from the U.S. Office of Surface Mining Reclamation and Enforcement (OSMRE) in 1982. The Commonwealth also has primacy for administering the National Pollutant Discharge Elimination System (NPDES) program for EPA and performs this function through the DER's Bureau of Water Quality Management (BWQM). Shortly after assuming primacy for the coal regulatory program, BMR took over most permitting functions for mining-related activities. However, BWQM develops water quality protection reports and advises BMR whenever more stringent water quality protection limits are necessary based upon existing state regulatory water quality standards. A toxic management plan is presently applied by BWQM in the permitting of industrial waste discharges (BWQM 1985). As a result of the 1985 EPA decision to exempt mining from toxics regulation, an attempt was made by the BMR in cooperation with BWQM to collect information on certain toxics thought to be prevalent within certain mining discharges (Bercheni 1985). Although results of this sampling effort were not available for review, permits are presently issued without prescribed toxic limits. The permittee is cautioned that should effluent standards be developed under Section 307(a) of the Clean Water Act, the permit may be amended to include these effluent standards.

The Pennsylvania Fish Commission (PFC) is an independent administrative Commission within the Commonwealth of Pennsylvania which has statutory responsibility for the protection and management of the Commonwealth's fish and aquatic life resources. The PFC provides the DER information in the mine regulatory review program to partially satisfy the Commonwealth's fish and wildlife protection responsibilities specified under the Federal Surface Mining Control and Reclamation Act (SMCRA). When the EPA and subsequent DER positions surfaced in 1985, the PFC had some immediate concern about the decisions to exempt toxics from mining regulation. Prior to 1982, certain toxic metals were routinely included by BWQM in the permitting of discharges from underground mines and coal preparation plants. Consequently to some degree, this decision for exemption was a change from existing policy. This change coupled with evidence showing that 12 out of the 14 metals on the EPA priority pollutant list accumulate in both sediments and biota (Chapman et al. 1982) gave rise to a justified concern about a potential environmental problem.

Early in 1986 the PFC was contacted by the U.S. Fish and Wildlife Service (FWS), Ecological Services Office, State College, PA, about possible candidate projects for funding in their Environmental Contaminant's program. This program includes an ongoing effort to identify contaminant "hot spots" that may be having an adverse effect on fish and wildlife. A monitoring plan was proposed by the PFC to address specific mine discharge points. A review of discharge monitoring reports to insure compliance of conventional pollutant limits was performed, DER staff was contacted for recommended monitoring sites, and a final list was developed prioritizing sites for sampling. Fairly continuous discharge types were preferred rather than short-term or intermittent discharges which are commonly associated with surface mining operations in case a chronic bioaccumulative problem existed which would result in higher, perhaps detectable concentrations in fish exposed to longer treatment periods. Funding for the analyses of 18 separate samples was approved and eventually 7 different sites were sampled (fig. 1). Site 1 was downstream from a NPDES discharge location from a refuse disposal site on Laurel Lick Run (Cambria County). Sites 2 and 3 were below NPDES discharge points from coal preparation plants on Quemahoning Creek (Somerset County) and Pine Run (Jefferson County). Sites 4, 5, 6, and 7 were downstream of NPDES permitted discharge points from underground mines on Dunkard Creek (Greene County), Tenmile Creek (Washington County), South Fork Tenmile Creek (Greene County) and Bark Camp Run (Clearfield County). The objective of the study was to determine if there was a potential residual toxic metal problem in fish located downstream of various coal mining wastewater treatment locations.

MATERIALS AND METHODS

Fish were collected by backpack electrofishing at seven sites located throughout the Pennsylvania bituminous coal region (fig. 1). Sites 1, 2, and 3 were sampled on August 26-27, 1986, and sites 4, 5, 6, and 7 were sampled on October 20-21, 1986. Stations were sampled downstream of any mixing zone established in the receiving stream to insure proper exposure at least at the time of sampling. It is recognized that some species are more transient than others which could affect their temporal and spatial distributions within the watershed. Attempts were made to search downstream areas to fill three samples per site including: 1) five whole bottom feeding fish; 2) five whole predator fish; and 3) five predator fish fillets. The number of sampling sites was ultimately controlled by a funding quota of 18 individual samples. Sampling station locations are described in table 1.

Fish were collected and identified in the field, measured to the nearest 0.1 cm, weighed to the nearest 0.1 gram, wrapped in aluminum foil placed in labeled plastic

Figure 1. Map of Pennsylvania showing sampling station locations within the bituminous coalfield.

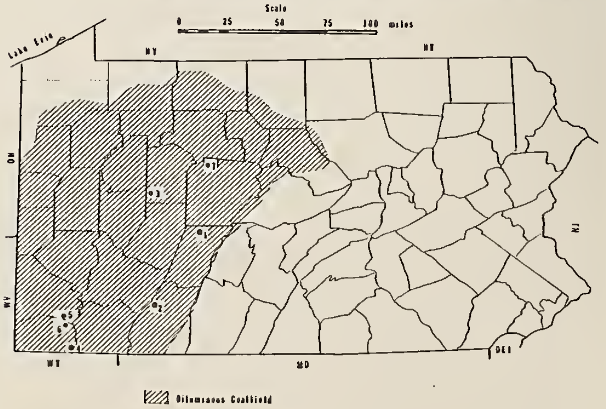


Table 1.--Sampling station locations.

SITE NUMBER	STREAM (FACILITY)	COUNTY	LOCATION
#1	Laurel Lick Run (Refuse Disposal)	Cambria	Route T-501 bridge
#2	Quemahoning Creek (Prep Plant)	Somerset	L.R. 55082 bridge
#3	Pine Run (Prep Plant)	Jefferson	L.R. 33005 bridge
#4	Dunkard Creek (Deep Mine)	Greene	3.3km downstream of L.R. 30074 bridge
#5	Ten Mile Creek (Deep Mine)	Washington	1.8km downstream of L. R. 62146 bridge in Marianna
#6	S. Fork Ten Mile Creek (Deep Mine)	Greene	1.0km downstream of L. R. 30050 bridge in Chartiers
#7	Bark Camp Run (Deep Mine)	Clearfield	0.6km upstream of PA Route 255 bridge

bags and transported on ice to the laboratory where they were frozen prior to shipment. Fish species, length, and weights of specimens collected from seven sampling sites are reported in table 2. Fish were shipped frozen on dry ice to the Mississippi State Chemical Laboratory at Mississippi State, MS for organochlorine pesticide and polychlorinated biphenyl (PCB) analysis and to the Environmental Trace Substance Research Center in Columbia, MO for selected toxic metal analysis. Both laboratories were subjected to a rigorous evaluation by a panel of U.S. FWS scientists.

RESULTS AND DISCUSSION

Results from the fish samples submitted for analysis included 26 organochlorine pesticides, polychlorinated biphenyls (PCB's) and 14 metals. The organochlorine pesticide group was either not detected or was detected at levels barely above analytical detection limits (0.01ppm) at Sites 1, 2, 3, 4, and 7. These sites were located in watersheds with limited drainage areas and sparse anthropogenic activity. However, detectable concentrations of either the parent compound or its derivatives were found for chlordane, DDT, and dieldrin at Site 5 on Tenmile Creek and Site 6 on the South Fork Tenmile Creek. Both station locations were in portions of the watershed downstream from various types of human development including agricultural activities. The Food and Drug Administration (FDA) has established action levels for chlordane, DDT and its derivatives, and dieldrin to control levels of contaminants in human food and animal food. Action levels are limits at or above which FDA will take action to remove contaminated products from the market. Prescribed limits for fish for chlordane, DDT, and dieldrin are 0.3ppm, 5.0ppm, and 0.3ppm, respectively (FDA 1981). Total chlordane concentrations were calculated by adding all isomers. Chlordane levels at Sites 5 and 6 ranged from 0.10ppm in a whole rock bass sample at Site 6 on the South Fork Tenmile Creek to the 0.30ppm action level in a smallmouth bass fillet sample at Site 5 on Tenmile Creek. Total DDT concentrations were computed by adding DDT isomers plus those of its derivatives, DDD and DDE. A maximum total DDT concentration of 0.11 was measured in the smallmouth bass fillet sample collected at Site 5 on Tenmile Creek, but did not approach the 5.0ppm action level. The maximum reported dieldrin concentration, 0.07ppm, was for a smallmouth bass whole fish sample from Site 6 on the South Fork Tenmile Creek. PCB testing revealed undetectable concentrations at all sites except Sites 5 and 6 in the Tenmile Creek watershed (table 3). The present FDA action level of 2.0ppm was not approached by any of the samples (U.S. EPA 1984). A maximum 0.40ppm was measured from a smallmouth bass whole fish sample collected at Site 6 in the South Fork Tenmile Creek.

Table 2.--Fish species, lengths and weights of specimens collected from seven sampling sites, August through October, 1986.

SITE	SPECIES (NUMBER)	SIZE RANGE (mm)	TOTAL WEIGHT (g)
#1	White Sucker(5) *Catostomus commersoni*	116-276	432
#2	Creek Chubs (5) *Semotilus atromaculatus*	93-158	114
#3	White Suckers (5)	164-193	276
	Creek Chubs (5)	130-184	174
#4	Smallmouth Bass (W)[a] (5) *Micropterus dolomieui*	247-302	1213
	Smallmouth bass (F)[a] (5)	211-304	1127
	N. Hogsuckers *Hypentilum nigricans*	167-252	465
#5	Smallmouth Bass (W) (5)	92-308	974
	Smallmouth Bass (F) (3)	264-294	864
	Rock Bass (4) *Ambloplites rupestris*	140-174	318
	Golden Redhorse (5) *Moxostoma erythrurum*	258-335	1206
#6	Smallmouth Bass (W)(5)	170-242	432
	Smallmouth Bass (F)(4)	220-324	766
	Rock Bass (4)	154-175	302
	N. Hogsuckers (5)	205-242	574
#7	Brook Trout (3) *Salvelinus fontinalis*	146-155	84
	Creek Chubs (5)	149-192	254
	White Suckers(5)	139-193	244

[a]-(W) signifies whole fish, (F) signified fillet.

Toxic metal analysis included testing for silver (Ag), arsenic (As), cadmium (Cd), copper (Cu), iron (Fe), mercury (Hg), molybdenum (Mo), nickel (Ni), lead (Pb), antimony (Sb), selenium (Se), thallium (Tl), vanadium (V), and zinc (Zn). Measurable concentrations were reported by the laboratory for all metals except Ag, Pb, or Tl and are presented in Table 3. Data were compared to 85th percentile numbers developed as part of the U.S. Fish and Wildlife Service's National Contaminant Biomonitoring Program (NCBP) which is an ongoing program where fish were collected at 112 monitoring stations throughout the U.S. from 1978 through 1981 to monitor temporal and geographic trends of chemical contaminants (Lowe et al. 1985). Organoleptic data (avoiding consumption because of poor taste or odor) from available literature, established ambient water quality criteria (U.S. EPA 1986), and FDA action levels (FDA 1981) were also used for comparisons. The 85th percentile values are only available for As, Cd, Cu, Hg, Se, and Zn. Levels were exceeded for Cd and Cu in creek chubs at Site 2; Cd and Cu in white suckers and creek chubs at Site 3; Hg in smallmouth bass fillets at Site 4; Cu in rock bass at Site 6; and Cu

Table 3.--Contaminant residues (ppm wet weight) in fish tissue collected at seven sampling locations throughout the Pennsylvania bituminous coalfields, August through October 1986.

Site	As	Cd	Cu	Fe	Hg	Mo	Ni	Sb	Se	V	Zn	PCBs
Species	ppm Wet Weight											
Site #1												
White Sucker	0.02	0.05	0.80	64.1	0.05	ND	0.23	0.04	0.61	0.11	18.7	ND
Site #2												
Creek Chub	ND	0.10	1.55	23.8	0.02	0.12	0.09	0.04	0.36	0.01	22.9	ND
Site #3												
White Sucker	0.04	0.07	1.21	164.8	0.07	0.35	0.35	ND	0.68	0.21	27.3	ND
Creek Chub	ND	0.11	1.88	33.9	0.06	0.07	0.17	0.07	0.50	0.02	27.4	ND
Site #4												
Smallmouth Bass	0.08	ND	0.58	18.9	0.16	0.05	ND	0.10	0.58	0.02	18.1	ND
Smallmouth Bass (F)	0.05	ND	0.32	>.3	0.24	ND	ND	0.17	0.49	0.01	13.9	ND
N. Hogsucker	ND	0.01	0.61	23.3	0.05	0.02	0.07	0.11	0.52	0.02	19.1	ND
Site #5												
Smallmouth Bass	0.08	0.02	0.55	36.4	0.11	0.08	0.18	0.13	0.66	0.02	13.0	0.29
Smallmouth Bass (F)	0.05	ND	0.37	7.3	0.17	ND	ND	0.05	0.54	ND	9.9	0.14
Rock Bass	ND	ND	0.82	690.7	0.10	ND	0.25	0.14	0.57	0.09	23.3	0.15
Golden Redhorse	0.03	0.01	0.52	50.7	0.06	0.17	0.18	0.10	0.55	0.03	19.8	0.20
Site #6												
Smallmouth Bass	0.05	ND	0.51	20.5	0.09	ND	ND	0.15	0.71	0.02	15.2	0.40
Smallmouth Bass (F)	0.07	ND	0.51	26.7	0.09	0.08	ND	0.12	0.71	0.02	14.4	ND
Rock Bass	0.05	0.01	1.31	26.1	0.08	0.05	0.05	0.11	0.54	0.05	21.2	0.24
N. Hogsucker	0.04	0.03	0.82	53.5	0.08	ND	0.16	0.07	0.47	0.08	30.9	0.19
Site #7												
Brook Trout (F)	0.02	0.03	1.23	35.5	0.05	0.60	0.17	0.10	0.41	0.05	28.8	ND
Creek Chub	ND	0.02	2.04	23.1	0.06	0.08	0.12	0.09	0.46	ND	20.3	ND
White Sucker	0.04	0.01	0.92	138.9	0.05	ND	0.54	ND	0.47	0.19	22.7	ND
85th Percentile	0.22	0.06	0.90		0.18				0.71		40.09	

Note: Whole Fish Values Unless (F) Indicating Fillets.
ND - Not Detectable.

in brook trout, creek chubs, and white suckers at Site 7. Although the 85th percentile numbers are not an established regulatory standard, they do serve as a warning system to alert resource managers to possible "hotspots" of environmental contamination. While figures 2 and 3 do not offer any statistical support to the significance of the problem because of the small sample size, they do illustrate that Cu and Cd are present in high enough concentrations at selected stations to be on concern when compared to the national database.

Figure 2. Copper concentrations (ppm wet weight) in selected whole fish samples.

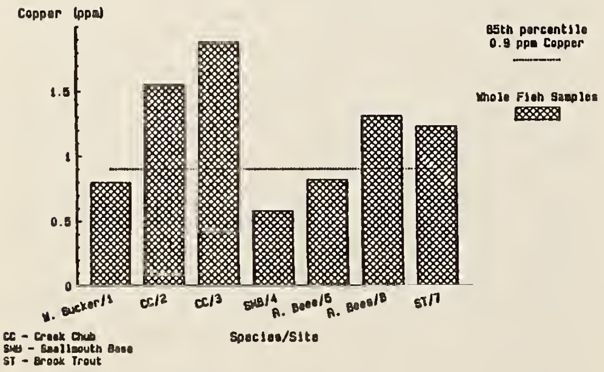
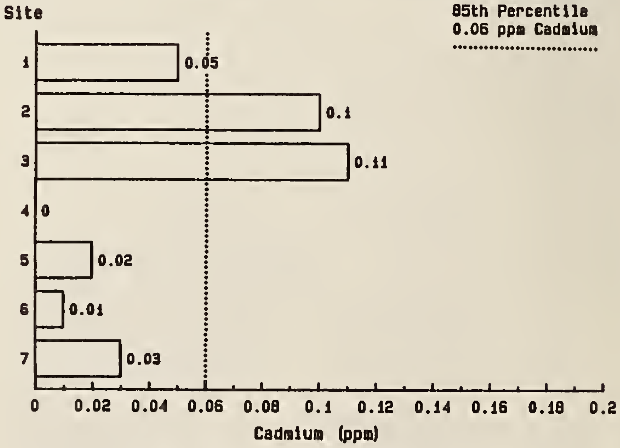


Figure 3. Cadmium concentrations (ppm wet weight) in selected whole fish samples.



Organoleptic data are scarce to nonexistent within the literature for most metals, and where it does exist, it relates primarily to drinking water and is difficult to interpret when found in fish tissue. This is especially true for certain metals such as Cu, Fe, Mo, Se, V, and Zn which can often have essential and beneficial uses in trace amounts in plant and animal nutrition (McKee and Wolf 1963). However, little is known about quantities, what forms are metabolized, how and where the elements are stored, and even less about overall mechanisms of action. These uncertainties combined with the wide array of various salts and oxides that can exist in the environment make the data difficult to interpret based on total metal concentrations. Copper, for example, has been reported to affect the taste of drinking water at concentrations in the range of 1.0-2.0 mg/L with 5.0-7.5 mg/L making water completely undrinkable (McKee and Wolf 1963). The brook trout (Site 7) and rock bass (Site 6) samples were the only two gamefish samples that might have possibly been affected by the palatability test. Comparing edible portions of gamefish samples collected at Sites 4, 5, 6, and 7 for Fe concentrations, all four sites exceed the 1.0ppm drinking water maximum which would make water unpallatable to drink (McKee and Wolf 1963). It is interesting to note that the smallmouth bass fillets collected at Sites 4 and 5 only contained 7.3ppm Fe whereas those collected at Site 6 contained 26.7ppm and the brook trout found at Site 7 were measured to have 35.5ppm.

Other nonessential nutritional metals such as As, Cd, Hg, Ni, Sb, and Tl pose more significant human health risks and are much more conspicuous by their presence in the sample analysis. The EPA (1986) developed ambient water quality criteria for all six of these priority pollutants, and sufficient information was available so that fish tissue consumption limits were developed for As, Hg, Ni, Sb, and Tl. These criteria can be used to assess the human health risks associated with the consumption of contaminated fish. Since As is the only metal of the group which is a known carcinogen, an incremental cancer risk factor of 10^{-6} was chosen by BWQM in Pennsylvania which places the criteria for consumption of aquatic organisms at 17.5 nanograms (ng)/L. A basic exposure assumption of a 70-kg male person consuming an average of 6.5g/day must be made for these criteria to be appropriate. Other criteria for the protection of public health against the ingestion of contaminated fish tissue include Hg at 146 ng/L, Ni at 100 micrograms (ug)/L and Sb at 45ppm.

These concentrations are extremely low, and all but Sb are exceeded in the edible samples collected in this study; however, sufficient populations of gamefish were not found downstream of any discharge point to be harvested in significant quantities to validate the exposure assumption. Additionally a 1.0ppm FDA action level exists for Hg which was not exceeded in any sample (FDA 1981).

CONCLUSIONS

Although the data presented in this study do not demonstrate an immediate public health threat from toxic metals, they do indicate the presence of an environmental problem which could be manifesting itself within resident aquatic communities based upon levels in excess of certain 85th percentile concentrations. More detailed study upstream and downstream of these discharges is necessary to define actual sources and quantify existing biological populations. Should further biological assessments verify that select discharges are affecting the biological uses of receiving streams by exceeding conventional pollutant loadings or introducing unregulated toxics, the regulatory authorities should address the problem by establishing site-specific limitations.

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BIG STONE GRANITE QUARRY HABITAT DEISGN: HSI RECLAMATION APPLICATION

Burley, J. B., S. Johnson, P. Larson and B. Pecka[1]

Abstract.--A West-central Minnesota granite quarry was studied to develop suitable post-mining land-use configurations. The quarry is adjacent to the federal Big Stone Wildlife Refuge. The primary post-mining land-use is projected to be wildlife habitat.

The study utilized recently developed Habitat Suitability Indexes (HSI) technology and other similar habitat models. This technology was incorporated into the reclamation process to generate design iterations and develop optimum design forms. With this technology, pre-mining conditions and post-mining alternatives can be numerically compared. The technology allows the targeting of cost effective and efficient habitat improvement. Plus it allows one to evaluate the effects of habitat improvements upon numerous species. In an economic manner, desired habitat improvements can guide mining operations, phasing, beautification, overburden placement, vegetation selection, wetland development and site amenities.

The HSI analysis indicated that the reclaimed quarry site could supplement existing refuge habitat conditions by adding several biophysical associations. The associations included a prairie grassland matrix, shrubland/woodland patches, wet meadow patches, open water matrix and emergent aquatic patches. Habitat scores were substantially improved ($p<.05$) for Great Egret (Egretta alba), Great Blue Heron (Ardea herodias), Western Grebe (Aechmophorus occidentalis), Wood Duck (Aix sponsa), White-tailed Deer (Odocoileus virginianus), Greater Prairie Chicken (Tympanuchus cupido americanus), Canvasback Duck (Aythya valisineria), Gadwall (Anas strepera) /Mallard (Anas platyrhynclos), Blue-winged Teal (Anas discors) Green-winged Teal (Anas crecca) Northern Shoveler (Anas clypeata) complex.

INTRODUCTION

The Big Stone quarry, operated by the Ortonville Stone Company is located approximately two miles southeast of Ortonville, Minnesota along State Highway 75 (Figure 1). The operation produces crushed stone for use as railroad ballast and construction aggregate.

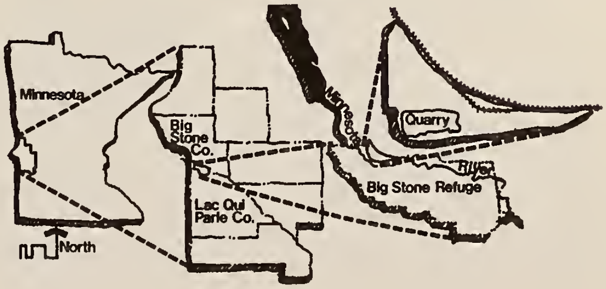

Figure 1. This series of maps illustrate the location of the granite quarry.

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Although mining operations at this mine will conceivably continue for over 80 years, granite quarrying is only a transitional land-use. The post-mining land-use should be carefully considered and developed in conjunction with the earth moving activities of the quarry operator; otherwise, the configuration of the post-mine landscape may be inappropriate with the intended post-mining land-use.

Burley and Thomsen (198-) have described the diversity of landform configurations associated with various post-mining land-uses. They illustrated the differences between these landforms. Optimum landforms for housing can be quite different from optimum landforms for wildlife.

At the Big Stone Quarry, the post-mining land-use with the highest potential for successful development is wildlife habitat. The quarry is adjacent to the Big Stone Refuge, operated by the United State Fish and Wildlife Service (FWS). According to the refuge's recent masterplan (FWS 1986), additional aquatic habitat, upland habitat and cavity nesting habitat is desired to complement the existing wildlife features within the refuge.

Opportunities for other post-mining land-uses are not as promising. Housing and industrial land-uses are not in demand for the area. In addition, the post-mining landscape potential for farmland is low. Shallow soils and the creation of a lake make agronomic farming impractical. Therefore, developing the landscape for wildlife is the most promising post-mining land-use.

Burley and Thomsen (198-) indicate that post-mining landscapes for wildlife are very species specific. A generic lake intended for fish is not adequate. The lake must have identifiable features and specific landscape patterns that match the habitat needs for the desired wildlife. The landscape created for pan-fish will be quite different from a lake intended for trout.

Habitat models are tools that can assist in developing a specific landscape prescription to meet the habitat requirements for desired wildlife.

Intent of Paper

This paper illustrates the application of habitat models to produce wildlife habitat post-mining land-use plans at the quarry. Many biologists, landscape architects and planners are still unfamiliar with these models and are unfamiliar with the potential these models possess in reclamation applications. It is important that reclamation specialists become acquainted with the significance and utility of these habitat models.

Habitat Models and Wildlife

The rapidly changing technology available to commercial and industrial interests today has created the need for a system in which landscape architects, ecologists and wildlife biologists can study the effects of proposed land management decisions upon wildlife habitat. Within the last ten years, species specific habitat models have been developed by the FWS, the U.S. Army Corps of Engineers and by several independent researchers. These models are equations which attempt to predict the suitability of a particular landscape pattern for a specific wildlife group or species. Verner, et al., (1986) recently edited Wildlife 2000: Modeling Habitat Relationships of Terrestrial Vertebrates. For individuals not familiar with wildlife models, this book is a good introduction to technical issues concerning habitat modeling. Burley (1983) illustrated an early use of habitat models for reclamation applications.

The models do have limitations. Many of the models are expert guesses concerning wildlife habitat requirements. Some of these models have been tested and require further refinement. Some models are based upon multiple regression techniques and have a potentially greater reliability. The models must be applied within the naturally occuring range for the selected species. The habitat scores obtained from the models are not exact population predictions but rather habitat scores indicating the relative suitability of the habitat to sustain a particular species. Despite these limitations, the models represent current knowledge and understanding about wildlife habitat needs and are useful tools to develop landscapes for wildlife.

Description of Study Area

The granite quarry is an exposed portion of the precambrian shield. The precambrian rocks became exposed by the Glacial River Warren. The post-glacial Minnesota River now occupies the valley created by the Glacial River Warren. The quarry is adjacent to the Minnesota River. Because the precambrian rocks are relatively impervious to water, the Minnesota River is the termination of groundwater flow from the Big Stone Lake Watershed (Cotter , et al., 1966) and the Pomme de Terre River Watershed (Cotter and Bidwell (1966).

Soils are shallow stony loams with numerous rock outcrops. This soil supports xeric prairie, lichen colonies and ball cactus (Mammilaria vivipera). In addition, wet forest (defined by Curtis 1959) occupy the land along the Minnesota River.

The quarry's mining operations contain several phases. First, surficial unconsolidated material is removed and stockpiled. Once the granite has been exposed, vertical holes are drilled using a rotary drill. The holes are filled with an explosive slurry. The active ingredient is ammonium nitrate. The explosive slurry is detonated and the granite is fractured into large boulders. A dipper shovel loads the granite boulders into trucks. The trucks haul the boulders to the primary rock crusher. From the primary rock crusher, the rock is moved by conveyor to a secondary rock crusher. The rock is then screened and sorted to produce crushed granite ranging in size from 2 inches to 1-3/4 inches in diameter. About 15 to 20 percent of the screened material remains as unmarketable fines. The marketable product is loaded into rail hopper cars ready for shipment. Unmarketable material can be utilized in reclamation operations. The granite will be extracted to a depth approximately 90 feet or more below the water table. This means that once the operations are complete, a large lake will occupy the quarry site. The volume of the unmarketable fines will not be of sufficient size to completely fill in the lake.

Reclamation planning and habitat modeling should determine the optimum landscape patterns for placement of unmarketable material in conjunction with the newly created lake.

METHODOLOGY

Figure 2 outlines the process employed to develop the post-mining land-use plan. Nine wildlife groups/species were selected for specific habitat improvement. Table 1 lists the groups/species studied and the modelling procedures employed.

Two types of habitat models were selected for use in the study. The first set were recent FWS models, Habitat Evaluation Procedures (HEP). A microcomputer version (Hays and Heasley 1986 and HEP Software support HEP Group (1985) assisted in the modelling effort. The key component of HEP is the Habitat Suitability Index (HSI). By rating the sites with HSI graphs and equations, proposed changes can be evaluated in a relatively objective and predicable manner. HSI procedures were the primary basis for most of the models utilized in this study. The other set of models were developed by Flood, et al., (1977), and are older FWS models.

The HEP models were transcribed into a format resembling the format presented by Flood (1977). In addition, some models were modified slightly with the removal or addition of habitat features. A copy of these equations and their format can be obtained by writing the authors of this paper.

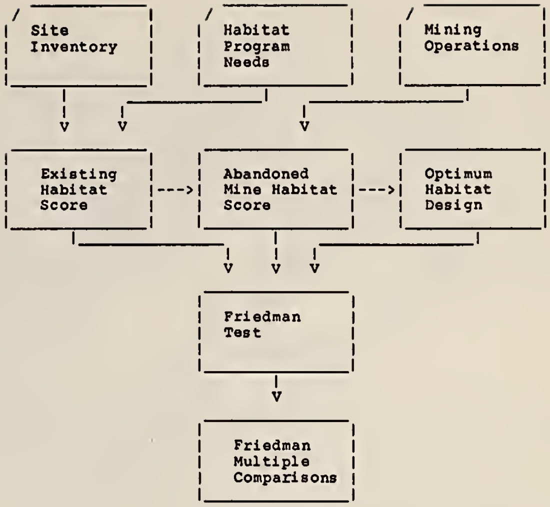

Figure 2. Flowchart of Habitat Design and Evaluation Process

Table 1. List of Species/Groups and Habitat Methods Employed.

WILDLIFE SPECIES/ GROUP	HABITAT EVALUATION METHOD
Great Blue Heron (*Ardea herodias*)	HEP/HSI (Short and Cooper 1985)
Great Egret (*Egretta alba*)	HEP/HSI (Chapman and Howard 1984)
Western Grebe (*Aechmophorus occidentalis*)	HEP/HSI (HEP Software Support Group 1985 and Hays) and Heasley 1986)
Wood Duck (*Aix sponsa*)	HEP/HSI (Sousa and Farmer 1983)
American Coot (*Fulica americana*)	HEP/HSI (Allen 1985)
White-tailed Deer (*Odocoileus virginianus*)	Pre-HEP (Flood et al., 1977)
Greater Prairie Chicken (*Tympanuchus cupido americana*)	HEP/HSI (Prose 1985)
Canvasback (*Aythya valisineria*)	HEP/HSI (HEP Software Support Group 1985 and Hays and Heasley 1986)
Gadwall (*Anas strepera*), Mallard (*Anas platyrhynclos*), Blue-winged Teal (*Anas discors*), Green-winged Teal (*Anas crecca*), Northern Shoveler (*Anas clypeata*)	HEP/HSI (Sousa 1985, Flood et al., 1977, HEP Software Support Group 1985 and Hays and Heasley 1986)

Three primary habitat treatments were studied. The first treatment was the 1986 existing site conditions. The second treatment was the post-mining condition. This condition would occur in approximately 2056 A.D. This treatment examines the hypothetical situation where no wildlife planning would occur. Under this condition, the mining operation would complete its extraction in 2056 and abandon the quarry. This second alternative is an important alternative to examine. Burley and Hopkins (1984) indicated that some abandoned mine configurations can be highly suitable to some wildlife populations. Therefore, there is the possibility that the abandoned post-mining landscape could be intrinsically suitable for the selected wildlife species without any or few modifications. The third treatment was the 2056 post-mining situation where the landscape was carefully reclaimed for the nine wildlife groups/species.

Friedman two-way analysis of variance by ranks and the Friedman multiple comparison procedure were nonparametric statistical methods employed to compare landscape treatments across groups/species (blocks). These statistical methods are illustrated by Daniel (1978). Nonparametric methods were selected because the data set could not satisfy the assumptions associated with parametric methods. The Friedman two-way analysis of variance by ranks is a distribution free test with few restrictions.

RESULTS

Table 2 lists the results of the habitat scores for the existing condition. Table 3 list the results of the habitat scores for the abandoned quarry situation. Table 4 lists the results of the habitat scores for the planned habitat situation.

The Friedman two-way analysis of variance by ranks (Table 5) revealed at least one habitat treatment was collectively better than the other treatments scores (p<0.5). The Friedman multiple comparisons procedure indicates that the planned habitat treatment yielded higher results. There was not enough statistical evidence to conclude that the existing situation and abandonment situation yielded different results.

Table 2. Habitat Scores for Existing Conditions

WILDLIFE SPECIES/ GROUP	HABITAT ACRES	HABITAT SCORE	TOTAL HABITAT SCORE
Great Blue Heron	2.10	0.11	0.230
Great Egret	4.00	0.21	0.840
Western Grebe	6.00	0.28	1.670
Wood Duck	2.10	0.25	0.525
American Coot	2.10	0.66	1.380
White-tailed Deer	12.00		4.680
Greater Prairie Chicken	136.10	0.30	40.830
Canvasback	2.10	0.00	0.000
Gadwall, Mallard, Blue/Green-winged Teal Northern Shoveler	2.10	0.17	0.357
		GRAND TOTAL HABITAT SCORE	50.51

Table 3. Hsbitst Scores for Absndonded Contition

WILDLIFE SPECIES/ GROUP	HABITAT ACRES	HABITAT SCORE	TOTAL HABITAT SCORE
Great Blue Heron	113.20	0.16	18.112
Grest Egret	15.00	0.23	3.450
Western Grebe	15.00	0.08	1.200
Wood Duck	113.20	0.00	0.000
American Coot	113.20	0.41	46.412
White-tailed Deer	59.60	0.55	32.780
Grester Prairie Chicken	99.80	0.40	39.920
Canvssback	113.20	0.20	22.640
Gadwall, Mallard, Blue/Green-winged Teal Northern Shoveler	113.20	0.25	28.300
		GRAND TOTAL HABITAT SCORE	192.81

Table 4. Habitat Scores for Optimum Habitst Condition

WILDLIFE SPECIES/ GROUP	HABITAT ACRES	HABITAT SCORE	TOTAL HABITAT SCORE
Great Blue Heron	113.20	0.87	98.031
Grest Egret	15.00	0.69	10.320
Western Grebe	15.00	0.78	11.745
Wood Duck	113.20	0.93	105.270
American Coot	113.20	0.99	111.610
White-tailed Deer	59.60	0.96	57.394
Greater Prairie Chicken	99.80	1.00	99.800
Canvasback	113.20	0.60	67.920
Gadwall, Mallard, Blue/Green-winged Teal Northern Shoveler	113.20	0.96	108.670
		GRAND TOTAL HABITAT SCORE	670.76

Table 5. Friedman Two-way Analysis of Varisnce Test and Friedmsn Multiple Comparisons Test

WILDLIFE SPECIES/ GROUP	EXISTING SITE	RANK	ABANDONED SITE	RANK	POST-DESIGN	RANK
Great Blue Heron	0.230	3.00	18.112	2.00	98.031	1.00
Great Egret	0.840	3.00	3.450	2.00	10.320	1.00
Western Grebe	1.670	2.00	1.200	3.00	11.745	1.00
Wood Duck	0.525	2.00	0.000	3.00	105.270	1.00
American Coot	1.380	3.00	46.412	2.00	111.610	1.00
White-tailed Deer	4.680	3.00	32.780	2.00	57.394	1.00
Greater Prairie Chicken	40.830	2.00	39.920	3.00	99.80	1.00
Canvasback	0.000	3.00	22.640	2.00	67.920	1.00
Gadwall, Mallard, Blue/Green-winged Teal, Northern Shoveler	0.357	3.00	28.30	2.00	108.670	1.00
	50.51	24.00	192.81	21.00	670.76	9.00

199.70 MINUS 135.00 = 64.70

If T> or = 9.46 (Z-stat), then there is enough evidence to support that the scores sre different at p< or = to 0.05.

TEST STATISTICS		COMPARISON RESULTS	
|EX-POST| =	15.00	EXISTING	---
|EX-ABAN| =	3.00	ABANDONED	---
|POST-ABAN| =	12.00	POST	---

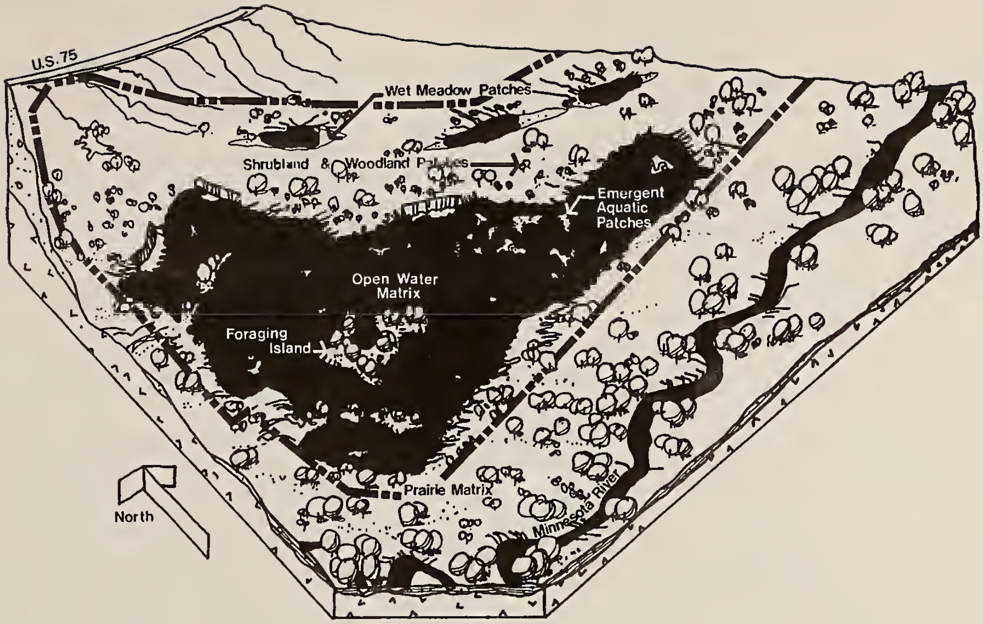

Figure 3. This drawing illustrates landscape patterns of a proposed post-mining land-use plan.

DISCUSSION

Figure 3 is a map illustrating the landscape patterns of the planned habitat treatment. The landscape includes a prairie grassland matrix, shrubland/woodland patches, wet meadow patches, open water matrix and emergent aquatic patches. Forman and Godron (1986) describe the landscape ecological terminology for defining matrixes and patches. This landscape pattern is considered to be an optimum configuration to meet the programing needs associated with the selected wildlife species/groups.

The open water matrix is a lake created by the mining operations. Under the abandonment treatment, the lake would be a large and deep open body of water suitable for only trout. This type of landscape would not be suitable for the waterfowl and shorebirds programed for the site. However, by adding emergent aquatic patches and patches of upland features in the waterbody, the open water matrix becomes suitable for programed species.

To create the suitable open water matrix, blocks of the quarried granite must remain intact. The blocks must be of sufficient height to rise above or near the surface of the waterbody. Leaving these blocks intact will reduce the volume of marketable crushed stone delivered from the quarry. The quarry operator may need to be monetarily compensated to leave this resource intact.

Within these islands, grassland and shrubland/woodland patches will create nesting habitat for American Coot, Mallard, Gadwall, Pintail, Green-winged Teal, Blue-winged Teal, Northern Shoveler, Wood Duck, Great Egret and Great Blue Heron. Emergent aquatic patches will provide foraging and rearing opportunities for these birds.

Beyond the open waterbody matrix, a grassland matrix with wet meadow patches and shrubland/woodland patches provide further foraging opportunities for selected waterfowl plus habitat for the Greater Prairie Chicken and for White-tailed Deer.

CONCLUSION

Habitat modeling allows the wildlife biologist, landscape architect and reclamationist the opportunity to study and compare various post-mining landscape treatments for a wide variety of wildlife habitats. The models create a very specific habitat program to develop a landscape. In the future, these models may become extensively incorporated into developing post-mining landscapes for wildlife.

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FATE OF AN ARTIFICIAL POND RECEIVING DRAINAGE FROM A RECLAIMED COAL REFUSE AND SLURRY AREA[1]

William S. Vinikour, Kirk E. LaGory, and Edwin D. Pentecost[2]

Abstract.--A pond was created as part of a reclamation effort at an abandoned coal mine near Staunton, IL. The pond was designed to help control runoff and to provide wildlife habitat. The benthic macroinvertebrates were analyzed as part of the site reclamation evaluation. Macroinvertebrates were collected from the newly created pond, a retention pond that received gob pile drainage, and a farm pond that served as a control. Reclamation activities began in 1976; samples were collected from the ponds in 1977, 1978, and 1987. Results from 1977 and 1978 indicated that the newly created pond was developing into a productive ecosystem. During those years, the benthos was dominanted by dipterans, especially chironomids. By 1987 the pH of the new pond had declined to below 2.5 and no invertebrates were found in the new pond or the retention pond. Phytoplankton was found in the new pond, but species richness and abundance were severely limited. Efforts to create viable aquatic habitats in slurry areas of abandoned coal mine sites may be subject to failure unless remedial actions, such as neutralization, are conducted on a regular basis.

INTRODUCTION

In the past, the methods and sites for disposal of coal-mine refuse were usually determined by convenience and economics. Coarse refuse (gob) was usually dumped near the preparation plant, which often created large, steep-sided piles. Effluent (slurry) from the coal washers was pumped into a nearby impoundment where solids were allowed to settle out. Many abandoned (pre-regulation era) refuse-disposal sites still present serious environmental, economic, and aesthetic problems. Conceivably, it could take hundreds of years for natural restoration of these acidic waste sites, during which time the surrounding environment would be adversely affected (Jastrow et al. 1984).

The U.S. Department of Energy, through the former Land Reclamation Program at Argonne National Laboratory, and two Illinois agencies -- the Abandoned Mined Land Reclamation Council and the Institute of Natural Resources -- developed a cooperative project to address the problems associated with reclaiming one of Illinois' abandoned deep mine refuse sites. Final land use for the area was to be a recreational area, wildlife habitat, and ecological education area.

As part of the reclamation activities, a 0.5-ha pond was created in the slurry area. This pond was designed to retain sediment and to develop into a productive aquatic community that could support fish and wildlife populations. The pond was constructed with deep (> 2 m) and shallow areas to provide a diversity of aquatic conditions that could support fish, benthic invertebrates, emergent vegetation, and a variety of wildlife. Two years following reclamation, the pond had shown signs of developing towards a productive community (Vinikour 1981). However, no monitoring or major site remedial actions occurred after that time. Given that ten years have past since initial site reclamation, it was deemed of value to assess the site and evaluate whether it currently is providing suitable invertebrate, fish, and wildlife habitat. This paper reports on the condition of the pond regarding its ecological value as a small pond habitat.

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STUDY SITE AND RECLAMATION ACTIVITIES

The site selected for the reclamation demonstration project was the abandoned Consolidated Coal Company's Mine No. 14 near Staunton in Macoupin County, IL. The total site included 13.8 ha, of which 9.3 ha had been affected by past mining operations and required reclamation. This included a 25-m-high gob pile that covered about 2 ha and a 4.5-ha slurry impoundment area. The dam for the slurry area was breached in the early 1940s, resulting in acid and sediment runoff from the site being transported about 0.8 km down a small stream to Cahokia Creek.

Reclamation activities began in September 1976, and the major effort was concluded by April 1977. The gob pile was extensively recontoured to reduce it to about one-fifth its original height. The slurry area was also recontoured, which included the excavation of a retention pond. Neutralizing/stabilizing agents were applied at a rate of 168 t/ha $CaCo_3$ equivalent and incorporated to a minimum depth of 15 cm into the recontoured refuse material. A 30 cm deep layer of soil cover material was then placed over the site. To this cover material, an application of 11.2 t/ha of agricultural limestone and 135 kg/ha each of nitrogen, phosphorus, and potassium was incorporated to a minimum depth of 10 cm (Vinikour 1981). The area was then seeded with a variety of grass and legume species (see LaGory et al. elsewhere in these proceedings).

MATERIALS AND METHODS

In June 1976, before any reclamation activities, a qualitative survey was made of the macroinvertebrates in standing bodies of water in the unreclaimed slurry area. Only a cursory search of the slurry area was conducted, and the observed aquatic or semiaquatic specimens were collected by hand.

During 1977, 1978, and 1987, benthic macroinvertebrates were collected from the three on-site ponds (fig. 1). The control pond was a small farm pond that was unaffected by the refuse or the reclamation work. It served as a control for benthic community comparisons with the new pond. It was assumed that the control pond would indicate the potential community that could develop in the new pond. The gob pile retention pond was sampled because, even after reclamation, its water quality typified acid mine drainage conditions. Knowledge of the invertebrates that inhabited this pond would indicate those organisms capable of inhabiting water degraded by acid mine drainage. By comparing the organisms in the three ponds, it could be determined whether only tolerant organisms were colonizing the new pond or whether more sensitive species were becoming established.

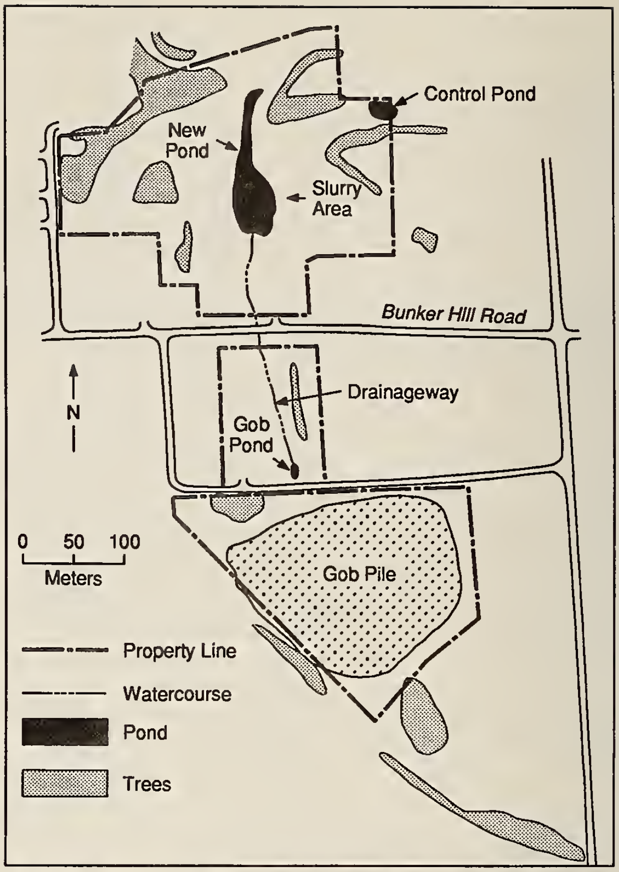

Figure 1.--Staunton reclamation site.

Pond benthic samples were taken with a Ponar grab in 1977 and with an Ekman grab in 1978 and 1987. Each device collected from a 0.023-m^2 area of pond bottom per sample. Most sampling was done along the shoreline in depths of 0.3 to 1.0 m. Collected samples were washed through a #30-mesh sieve with the unsieved portion, including organisms, preserved in 70% ethyl alcohol. Routine sample sorting and taxonomic identifications were conducted in the laboratory (Vinikour 1981). Shannon-Weaver diversity values (logarithmic base 2) were calculated following procedures in Brower and Zar (1977).

Phytoplankton samples were obtained from the new pond and control pond in 1987 by taking near surface water samples. Lugol's solution was added to the samples as a preservative. Algae were identified to the lowest taxonomic level possible using microscopic examination. Ciliated protozoans were also enumerated.

RESULTS AND DISCUSSION

The survey of the unreclaimed slurry area revealed that few aquatic species inhabited the standing water bodies. The only true aquatic species found was the water strider, Gerris sp. (Hemiptera: Gerridae). The only other species encountered was the variegated mud-loving beetle Lanternarius brunneus (Coleoptera: Heteroceridae). This semiaquatic beetle was collected from its galleries surrounding many of the water bodies in the slurry area. Species of this beetle family have not been previously reported to inhabit coal slurry and/or such extreme chemical conditions (e.g., pH < 4.0, acidity > 4,400 mg/L) (Vinikour 1979).

In the 1977 and 1978 samples, dipterans were the only organisms collected from the gob pond, the most abundant organisms in the new pond, and numerically dominant on all but one sampling occasion in the control pond. Chironomidae was the most prevalent family of Diptera. Eighteen chironomid taxa were collected from the ponds, with the major taxa being Chironomus plumosus, Procladius sp., and Tanypus punctipennis. Chironomus plumosus was the only species collected in abundance from the gob pond and was often the dominant species collected from the new pond. This was expected, considering degraded water quality in the gob pond (e.g., pH was < 4.5, alkalinity was 0.0 mg/L, and acidity ranged from 72 to > 29,500 mg/L) and the poor-to-fair water quality of the new pond (e.g., pH ranged from 4.0 to 8.4, alkalinity from 0.0 to 46.0 mg/L, and acidity from 0.0 to 28.0 mg/L). Harp and Campbell (1962) observed C. plumosus to be the only chironomid species in water with a pH of < 6.0. Other dipterans regularly collected were species of Ceratopogonidae and Chaoboridae.

In the 1977 and 1978 samples from the control pond, the fingernail clam Musculium partumeium and the snail Physa gyrina were commonly collected. They were absent (clams) or rare (snails) in the new pond because of inadequate water quality, substrate limitations, and/or physical constraints in colonizing the pond. The aquatic worm Limnodrilus hoffmeisteri was also common in the control pond, but absent in the new pond. Several dragonfly (Odonata), mayfly (Ephemeroptera), and beetle (Coleoptera) species were frequently collected, but in low numbers, from both the new and control ponds. These three insect orders contain species that are highly tolerant to extremes of water quality and/or are so highly mobile that they may enter or leave a body of water at will (Roback 1974). The mayfly genera present in the new pond (Caenis, Callibaetis, and Hexagenia) are also more resistant to pollution (Edmunds et al. 1976). The limited benthic community composition of the new pond during the 1977 and 1978 period resembled that reported from several of the acid strip-mine lakes found in Grundy County, IL (Master 1979). Severely degraded water quality, indicative of acid mine drainage, in the gob pond limited its benthic fauna to low densities of C. plumosus and to sporadic occurrences of a few other tolerant dipteran larvae (e.g., the cranefly Erioptera).

Benthic densities in 1977 and 1978 were generally greater in the control pond than in the other ponds, and the lowest densities always occurred in the gob pond. Also, diversity values were always highest in the control pond, while the gob pond usually had the lowest values (e.g., median diversity values were 2.8 in the control pond and 1.9 in the new pond; while values in the gob pond were < 1.0 on all occasions). The higher benthic diversities in the control pond were probably due to its better water quality, developed macrophyte assemblage, and abundance of allochthonous leaf litter. Living plant matter (excluding cattails) and detrital plant matter were sparse in the other ponds. Macrophytes and leaf litter provide diverse habitat and food resources for macroinvertebrates, allowing development of a fauna that encompasses a variety of functional feeding and habit groups (Cummins 1978). Although an abundant stand of cattails (Typha latifolia) was present in the new pond, and although some insects (e.g., Chironomus, mosquitoes, and beetles) thrive near cattails, this plant often prevents other macrophytes from growing in shallow areas (Lackey 1939). However, cattails are conducive to the presence of muskrats, which were observed in the new pond in 1978.

In theory, grading and covering coal refuse material should decrease pyrite oxidation rates, reduce acid formation rates, and improve water quality of site discharges. For this to be successful, prevention of erosion is important to (1) reduce exposure of refuse and subsequent development of acidic runoff, and (2) reduce water percolation and oxygen diffusion into the underlying refuse, thereby reducing pyrite oxidation and acid leachate formation (Jastrow et al. 1984). However, water percolation and oxygen diffusion into the waste material may occur even if soil cover is sufficient to control erosion. Water quality samples taken in 1979 and 1980 indicated that the new pond was beginning to acidify (i.e., pH < 4.2). It was thus expected that the new pond would maintain a low diversity and contain mostly species that are tolerant of acid mine drainage conditions (Vinikour 1981).

During the 1987 site survey, a number of acid seeps were observed throughout the site and somewhat severe erosion was evident along the main drainage leading from the gob pile to the new pond. The 1987 pond survey revealed that water quality and community composition of the new pond had deteriorated further. Water quality, as typified by a pH < 2.5 in the new pond, indicated a condition of severe acid mine drainage. The abundant stand of cattails that was thriving within the pond in 1978 had completely died off, with only encrusted stems remaining. Only a sparse population of living cattails occurred along the banks of the pond. A dense stand of reed phragmites (Phragmites maximus) occurred along a low lying area surrounding and north of the new pond drainage weir; but was not found around the perimeter of the new pond.

No benthic macroinvertebrates were collected in the Ekman grab samples and no neustonic species were observed in the pond during the several days of the 1987 site survey. Benthic samples did contain a few partial exoskeletons of corixids and head capsules of the midge Chironomus plumosus. Both of these organisms are common to less acidic waters and indicate that water quality conditions had been biotically-limiting for some period of time. Chironomus plumosus is often the only species reported in strip mine lakes with a pH < 6.0. It can be found in lakes with a pH < 3.0, but apparently does not complete its life cycle under such conditions. Also, it was only found under these severe low pH conditions when leaf detritus was present (Harp and Campbell 1962). No leaf detritus was observed in the new pond in 1987. Two generations of Chironomus plumosus normally occur each year, with emergence in mid-May and late July or August (Hilsenhoff 1967). Thus, if Chironomus plumosus was still extant in the new pond, larvae would have been expected to have been collected in early July. No remains of other macroinvertebrates that were collected in 1977 and 1978 were found (e.g., mayflies), indicating that these species had probably not inhabited the pond for a number of years. As the pH of the pond was < 4.2 in 1980, it can be assumed that the pond contained a very limited benthic community over the past eight years. Similarly, no benthic macroinvertebrates were collected from the gob pond. The pH of the gob pond was 3.2 in 1987, indicating that drainage from the gob pile has continued to be very acidic regardless of reclamation efforts.

Benthic species composition and diversity of the control pond were quite depressed in 1987. The only benthic species collected were Musculium partumieum, Physa gyrina, Limnodrilus hoffmeisteri, Polypedilum, Ablabesmyia, and Palpomyia; benthic macroinvertebrate diversity was 0.1. The high pH of the pond (7.8), coupled with the presence of the acid-intolerant molluscs (Musculium and Physa) and an abundance of amphibians in all stages of development, indicate that this suppression was due to factors other than acid mine drainage conditions. For example, the bottom of the pond was composed of an organic muck with little of the leaf litter and other coarse detrital matter that was abundant in 1977 and 1978. Also, submerged macrophytes were completely absent in 1987. The surface of the pond was entirely covered with duckweed. Such conditions have been reported to limit the occurrence of mosquito larvae (Angerilli and Beirne 1980), and may be largely responsible for the paucity of chironomids observed in 1987.

Phytoplankton collected in 1987 from the control and new ponds are listed in table 1. The samples indicate that the new pond is extremely depauperate. None of the species typically found in waters of low productivity were present (e.g., chrysophycean flagellates, diatoms, or desmids). Also, no visible sestonic organic matter was found in the new pond. Primary productivity due to suspended algae is essentially zero in the new pond. In comparison, the phytoplankton of the control pond was rich and diverse. The abundance of euglenophycean flagellates and ciliates indicate that the control pond may be organically enriched, although the high abundance of blue-green algae indicates that the organic enrichment is not necessarily accompanied by nitrate enrichment. The control pond does lack some algal types usually present in warm, productive, shallow ponds (e.g., Scenedesmus, chrysophycean flagellates, and centric diatoms)(Stull, pers. comm. 1987).

CONCLUSIONS

The new pond did not support a viable aquatic community ten years after reclamation activities were completed. The only benefit that the pond provides to terrestrial wildlife is related to the development of willows and other woody species around the perimeter of the pond. Slight-to-moderate acid mine drainage conditions were evident in the new pond after the initial two years following site reclamation. This condition was primarily responsible for the limited diversity and density of macroinvertebrates in the pond at that time (Vinikour 1981). Vinikour (1981) concluded that persistence of water quality conditions noted in 1979 (e.g., pH < 4.0) would limit the biota of the new pond to those species that can tolerate acid mine drainage conditions. Conditions since 1979 have continued to deteriorate to the point where the pH in the pond was less than 2.5, with no macroinvertebrates collected from the pond. Not even neustonic species such as water striders or water boatman were observed in the pond.

The new pond has functioned as a settling basin for sediment eroded from the site. This is viewed as a major benefit to the nearby receiving stream Cahokia Creek. Acid mine drainage discharge and sedimentation (including coal fines) to the stream have been kept in check without the need for any onsite mitigative measures for the past ten years. However, the lack of on-

Table 1.--Phytoplankton and ciliate protozoans of the new pond and control pond collected on July 7, 1987.

Taxa or Type	Abundance (number/ml)[1] New Pond	Control Pond
Anabaena sp.	--	P
Merismopedia trolleri	--	5,000
Microcystis incerta	--	4,000,000
coccoid blue-green algae	1,000	80,000
lunate blue-green alga	--	P
Euglena acus	--	P
Euglena oxyuris	--	200
Phacus acuminatus	--	100
Phacus helikoides	--	200
Phacus triqueter	--	300
Trachelomonas dybowskii	--	300
Coscinodiscus lacustris	--	P
Achnanthes sp.	--	P
Fragilaria sp.	--	P
Navicula sp.	--	P
Nitzschia sp.	--	P
pinnate diatom, < 10 microns long	--	3,000
flagellates, < 4 microns long	1,000	30,000
ciliates	--	2,000

[1] P = present, but in too few numbers to accurately determine an abundance value, -- = not observed.

site mitigative measures have prevented the new pond from developing into a productive ecosystem. Creation of a viable pond, or any other type of wetland, in a reclaimed slurry area is difficult to accomplish, especially if remedial actions are not regularly employed. Leedy (1981) stated that waters with a pH of 4.5 or lower would require repeated applications of lime to maintain a desired pH of 6.0 or greater, with additional lime needed whenever the pH falls below this level. Without such efforts, surface runoff from acid seeps and lateral movement of acidic water through the buried slurry wastes would lead to the eventual degradation of water quality, as was observed in the new pond. It is recommended that reclamation planning efforts include methods to ensure good water quality in wetland areas that are to be developed in abandoned slurry areas for more than the first few years. This must include the inclusion of periodic site evaluations and, if necessary, remedial actions.

ACKNOWLEDGMENTS

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ENVIRONMENTAL MANAGEMENT FOR LIMESTONE QUARRIES IN JAPAN

Hisakazu Oguri, Hiroshi Kaburaki, Kenji Moriyama[1]

Abstract.--In Japan, most limestone is obtained by surface mining. At Nihon Cement's Garo Quarry (capacity 500,000mt/mo) in Hokkaido, special measures for environmental management (accounting for approximately 9.8% of operating costs), such as a bank encircling the working face, stratified piling in the dump, water control, and revegetation have been adopted. The quarry continues to operate smoothly without pollution problems. Trees growing just outside the bank are not felled immediately to protect the scenic beauty; runoff is prevented from flowing outward by the bank. One-meter layers of waste in the disposal dump are well compacted. The dump is divided into several separate sectors, with disposal carried out on a rotating basis; grass is temporarily planted in idle sectors. Generation of polluted water is minimized. Polluted water is collected and led to precipitation ponds via hillside ditches and surface conduits; after filtration and sedimentation, water is discharged to the river. In the dump, revegetation is carried out in the completely filled sectors by first sowing grasses, i.e. Kentucky 31 fescue (Festuca elatior var. Arundinacea WIMM.), white clover (Trifolium repens LINN.), and/or redtop grass (Agrostis alba LINN.), and then by planting saplings such as wild black alder (Alnus japonica) and white birch (Betula tauschii) on plane steps. The step revegetation, wall-hole, and frame and sprayed soil-and-seed methods are used for slope revegetation in other quarries in Japan; at Osaka Cement's Ibuki Quarry, transplantation of the originally existing plants has been introduced. Environmental management is one of our foremost concerns and we must do our utmost to prevent our activities from resulting in environmental pollution.

INTRODUCTION

In Japan, all enterprises are strictly required to coordinate their industrial development and operation with conservation of the natural environment. The development and operation of limestone quarries is no exception. There are several peculiarities related to the locations of mines and the carrying out of related environmental controls on mining activities. Japan is a small, but highly industrialized, densely populated country where agriculture is still important. Because

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Table 1.--Annual production of Japan's 104 main limestone quarries. (in thousands of metric tons)

Year	Surface mining		Underground mining		Total
	Prod.	Pct.	Prod.	Pct.	
1985	140,267	99.5	689	0.5	140,996
1986	133,332	99.4	686	0.6	134,996
1987	130,856	99.4	807	0.6	131,663

of its complex geological situation, many types of ore deposits are found and mined there, and many of these deposits are near populated areas. In addition, most of the limestone quarries in Japan use the surface mining method (table 1), and many quarries are located near scenic spots. Therefore, our exploitation of limestone must be carefully balanced with conservation of nature through such methods as revegetation of quarried areas.

The existence of vegetation and forests is fundamental to human life; these resources exert controls on the population by affecting the water in rivers and preventing soil erosion, as well as by being natural air cleaners. Of course, the emotional effects such as improving the appearance of the surroundings are also important. On the other hand, it must be recognized that utilization of the world's finite mineral resources is just as necessary to society as is the reasonable growth of industry. Conservation of the natural environment involves a wide range of problems. Since surface mining causes changes in the environment, industrial projects must be coordinated with conservation efforts.

DEVELOPMENT OF GARO LIMESTONE QUARRY

Location and Climatic Conditions

Garo Quarry is located 7km northwest of NCC's (Nihon Cement Co., Ltd.) Kamiiso Plant, which is 10km west of Hakodate City, a major port on Japan's northernmost island, Hokkaido (figure 1).

Climatic conditions at Garo Quarry are shown in table 2.

Table 2.--Climatic conditions at Garo Quarry.

Item	Remarks
Average Temp.	8°C (46.4°F)
Maximum Temp.	33°C (91.4°F)
Minimum Temp.	-18°C (-0.4°F)
Rainfall	1,160mm
Snow (Nov. to Mar.)	About 3m deep

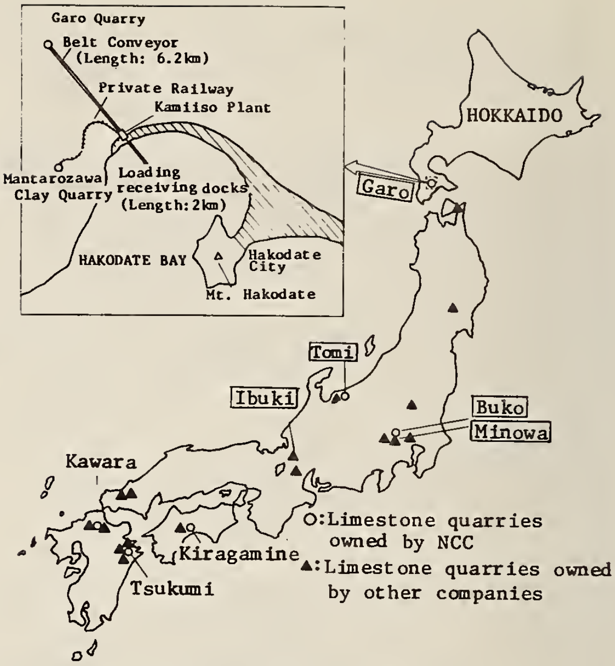

Garo Quarry
Belt Conveyor (Length: 6.2km)
Private Railway
Kamiiso Plant
Mantarozawa Clay Quarry
Loading receiving docks (Length: 2km)
HAKODATE BAY
Hakodate City
Mt. Hakodate
HOKKAIDO
Garo
Tomi
Ibuki
Buko
Minowa
Kawara
Kiragamine
Tsukumi
O:Limestone quarries owned by NCC
▲:Limestone quarries owned by other companies

Figure 1.--Location of Garo Quarry.

Geology

The structure of Garo limestone deposit is shown in figure 2.

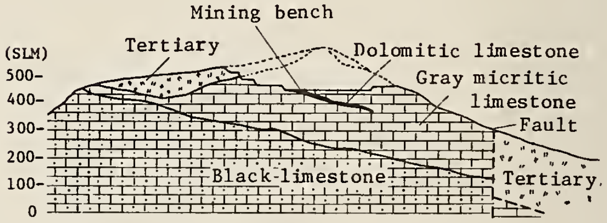

Mining bench
(SLM)
500-
400-
300-
200-
100-
0
Tertiary
Dolomitic limestone
Gray micritic limestone
Fault
Black-limestone
Tertiary

Figure 2.--Section of Garo limestone deposit.

The limestone deposit, consisting of massive distributions of gray micritic and black mesozoic limestone with intercalations of dolomitic limestone, is an anticlinal dome shape partially disturbed by folding and faulting. The tertiary formation which widely overlays the limestone deposit to a maximum thickness of 70m consists of well-stratified basic conglomerate, mudstone, and tuffaceous sandstone.

Basic Development Concept

Garo Quarry was opened in 1890 to supply limestone for cement to the Kamiiso Plant. As the plant expanded its

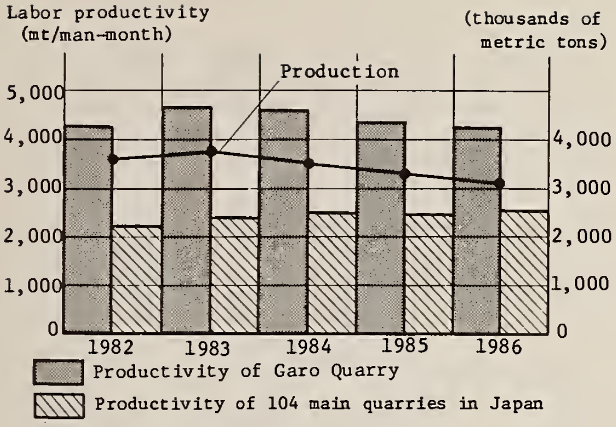


Figure 3.--Limestone productivity (1982-1986).

level of production, the quarry kept pace. Development of the new Hekirichi area was begun in July 1974, and practical operation started in January 1978. The Garo Quarry project was undertaken with several basic development concepts in mind, including: a monthly limestone production capacity of 500,000mt, achievement of high productivity (figure 3), prevention of pollution, and coordination with the surrounding natural environment.

ENVIRONMENTAL MANAGEMENT MEASURES

Bank Encircling Quarry Bench

A bank (guard wall) 5 to 10m high is formed around the quarry, making it virtually impossible to see the quarry from the outside. Trees growing just outside the bank are not felled until immediately before it is levelled (figure 4) in order to protect the scenic beauty. In addition, the bank, inside which rain and melted snow evaporate, serves to prevent river pollution due to runoff.

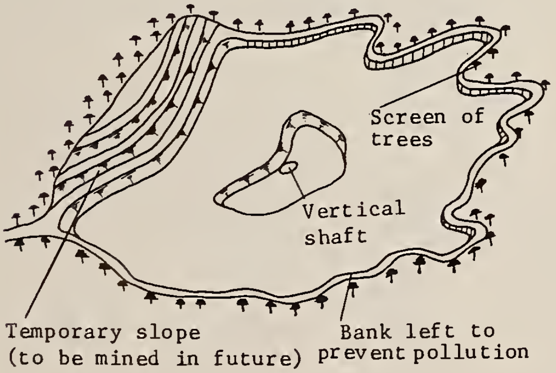

Screen of trees
Vertical shaft
Temporary slope (to be mined in future)
Bank left to prevent pollution

Figure 4.--Quarrying method.

Overburden Disposal Dump

The overburden disposal dump is designed to meet government construction standards. It has a capacity of 15 million mt (7.9 million m^3) and will cover an area of 23.8ha (58.8 acres) and reach a height of 450m above sea level in the future. Based on our experience, the following measures have been adopted: one-meter layers of waste are compacted with a compacting roller, thus reducing them to about 80% of their original volume (figure 5); the disposal dump is divided into three or four separate sectors, with disposal carried out on a rotating basis; in dump sectors not in immediate use, temporary ditches for runoff are dug, covered with vinyl sheeting to prevent surface collapse, and temporarily planted with grass; vegetation is planted and seeds sprayed in the completely filled sectors (figures 5 and 6). Approximately 9.5 million mt of overburden have been stripped and 28 million mt of limestone produced. The quarry continues to operate smoothly without pollution problems, and pollution prevention is seen as successful.

Water Control

The water control system at the Garo Quarry is shown in figure 7. At the Hekirichi working face, runoff is led to the lowest bench via the natural slope and the face-connecting road for evaporation. Water is prevented from flowing outward by the bank encircling the bench. In the Garo overburden disposal dump, generation of polluted water is minimized by the use of sectional stratified piling and temporary and standard revegetation procedures. Polluted water is collected and led to precipitation ponds via surface conduits, temporary surface ditches, and underground conduits. Spring water, rainwater that is from undeveloped areas or from near the disposal area, and polluted water from the mine road are collected via hillside drainage ditches and led to the precipitation ponds.

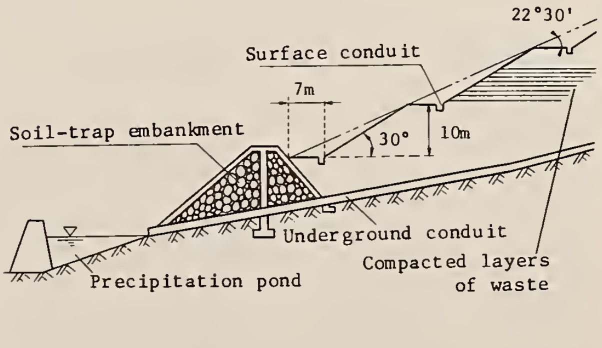


Figure 5.--Cross-section of overburden dump.

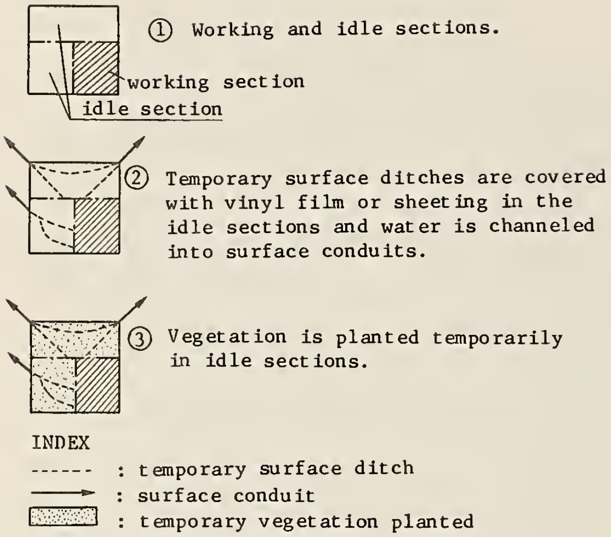

① Working and idle sections.
working section
idle section
② Temporary surface ditches are covered with vinyl film or sheeting in the idle sections and water is channeled into surface conduits.
③ Vegetation is planted temporarily in idle sections.
INDEX
------ : temporary surface ditch
⟶ : surface conduit
▨ : temporary vegetation planted

Figure 6.--Sectional stratified piling method.

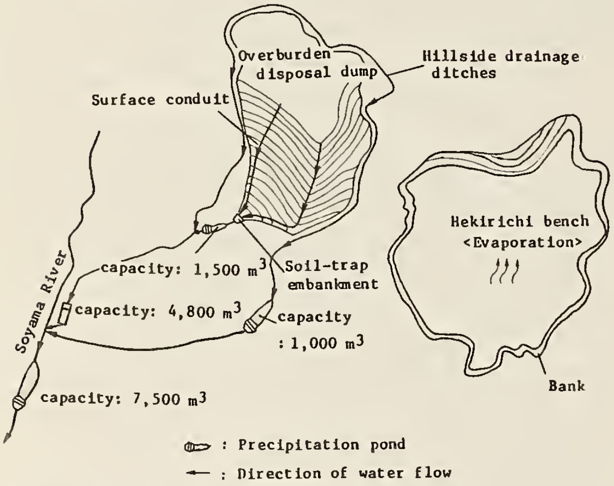

Overburden disposal dump
Hillside drainage ditches
Surface conduit
Hekirichi bench
<Evaporation>
Soyama River
capacity: 1,500 m3
Soil-trap embankment
capacity: 4,800 m3
capacity : 1,000 m3
Bank
capacity: 7,500 m3
: Precipitation pond
: Direction of water flow

Figure 7.--Water control system.

Water is discharged to the river after filtration and sedimentation. Precipitation ponds are wide and shallow to allow for easy dredging.

Revegetation

The final goal of revegetation is to return the natural environment to the state that existed in the local area before development. Reforestation is impossible in a short period of time, and conditions worsen with continuing operations; therefore, the short-term aim of revegetation must be primarily to replant the basic vegetation to promote long-term natural restoration of the environment.

Sowing of grass seed and planting of saplings in the overburden disposal dump at Garo Quarry are carried out in sections in the order in which piling is completed.

First, Kentucky 31 fescue (Festuca elatior var. Arundinacea WIMM.), white clover (Trifolium repens LINN.), and/or redtop grass (Agrostis alba LINN.) are sown. After preventing surface collapse with rapidly growing grasses, saplings such as wild black alder (Alnus japonica), white birch (Betula tauschii), white fir (Abies concolor), and wild cherry (Prunus serotina) are planted on plane steps. Recent data on revegetation at the dump is shown in table 3.

At Mantarozawa Quarry, which supplies clay material for the Kamiiso Plant, successful revegetation of the quarried area, primarily with wild black alder, but also with some white birch and larch (Larix) saplings, has been carried out since 1982 (table 4). The layout of Mantarozawa Quarry is shown in figure 8.

As there is little data on final slope revegetation at Garo Quarry because of limited experience, actual examples of final slope revegetation at other limestone quarries in Japan are substituted.

Ibuki Quarry (Osaka Cement Co., Ltd.), famous in Japan for its pioneering revegetation procedures, was developed in

Table 3.--Revegetation at Garo disposal dump.

Year	Area sown (m²)	Temporary area sown (m²)	No. of saplings planted
Pre-1984	62,000	329,000	9,630
1984	16,000	81,000	1,100
1985	16,600	85,600	1,070
1986	13,400	48,000	1,050
1987	15,500	44,000	1,200
Total	123,500	587,600	14,050

Table 4.--Revegetation at Mantarozawa Quarry since 1982.

Year	Revegetated area (m²)	No. of saplings	Reforested area (m²)[1]
1982	18,759	5,400	32,068
1983	20,436	4,590	
1984	7,710	2,570	----
1985	2,650	875	----
1986	500	190	10,332
1987	1,200	300	----
Total	51,255	14,285	42,400

[1] Area approved by government agencies.

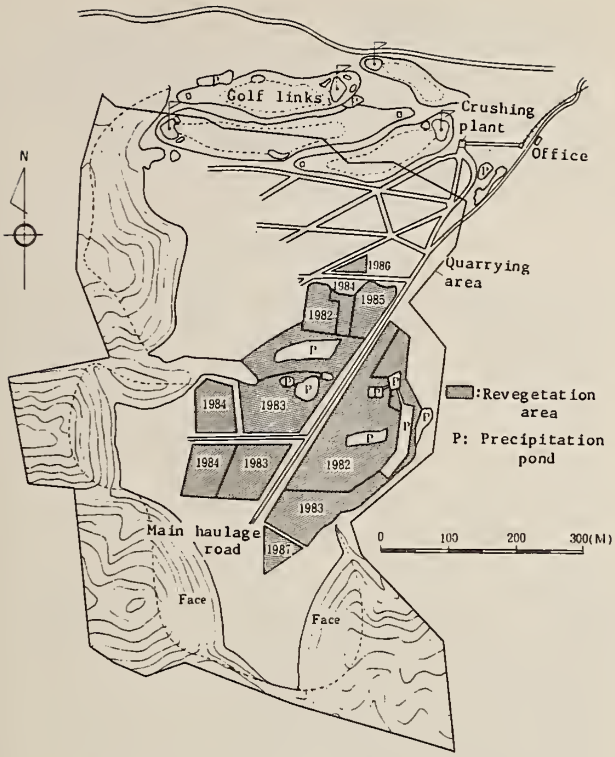
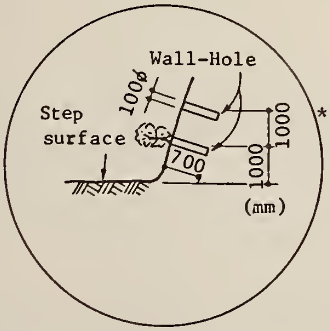

N
Golf links
Crushing plant
Office
1986
Quarrying area
1984
1985
1982
P
1984
1983
1984
1983
1982
1983
1987
:Revegetation area
P: Precipitation pond
Main haulage road
0 100 200 300(M)
Face
Face

Figure 8.--Layout of Mantarozawa Quarry.

1951 to supply limestone to Ibuki Cement Plant (current limestone supply capacity: 350,000mt/mo). Various procedures were tried; the eventual method of slope revegetation mainly consists of transplanting the originally existing plants. The procedure is as follows: original vegetation is investigated; the bench is prepared; surface soil is transported; a fence to prevent snowslides is constructed; the originally existing plants are transplanted, and the area watered and fertilized; seeds are then collected and pre-grown in a nursery; finally, the revegetation is reinvestigated and the cycle begins again from preparation of the bench. The revegetated area of the quarry totals 305,000m^2 to date (table 5), and the results have been widely acclaimed.


Wall-Hole
Step surface
100φ
700
1000
1000
(mm)

* Wall-holes are drilled in a staggered pattern (at Buko and Minowa Quarries)

Figure 9.--Standard wall-hole revegetation method.

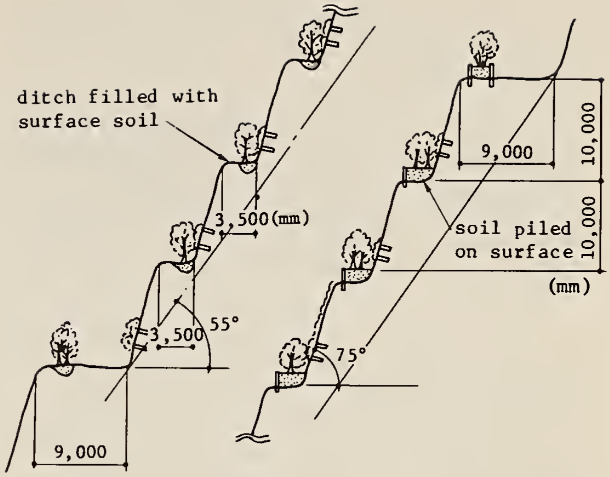

ditch filled with surface soil
3,500(mm)
3,500
55°
9,000
9,000
10,000
10,000
soil piled on surface
(mm)
75°

Figure 10.--Standard step revegetation method (at Buko and Minowa Quarries).

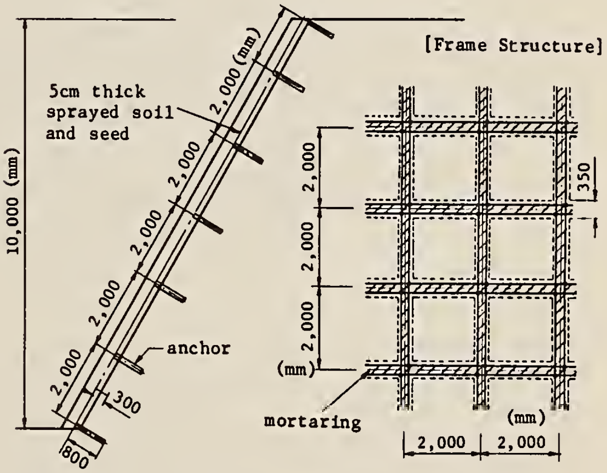

[Frame Structure]
5cm thick sprayed soil and seed
10,000 (mm)
2,000 (mm)
2,000
2,000
2,000
2,000
anchor
300
800
2,000
2,000
2,000
(mm)
350
mortaring
(mm)
2,000
2,000

Figure 11.--Standard frame and sprayed soil-and-seed method (at Tomi Quarry).

Table 5.--Revegetation at Ibuki Quarry since 1971.

Year	Revegetated area (m²)	Transplanting (m²)	Other methods (m²)
1971-80	206,890	139,990	66,900
1981	15,050	15,050	----
1982	12,000	12,000	----
1983	12,630	12,630	----
1984	18,330	18,330	----
1985	16,410	16,410	----
1986	23,678	23,678	----
Total	304,988	238,088	66,900

OPERATING COSTS

A breakdown of limestone production costs by percentage for Garo Quarry is shown in table 6.

Table 6 shows that special measures such as stripping and stratified piling, introduced to protect the natural environment, represent 9.8% of the raw-material production costs, a rather substantial increase over quarrying costs without environmental protection measures.

In general, achievement of low-cost operation is the fundamental goal of private enterprise. Efforts to achieve low-cost operation must include environmental protection measures through improvement of stripping and piling procedures, revegetation procedures, and the possible use of overburden piled in the dump as a material for cement, with the aim of turning expenditure into income. No goal can be achieved without technology.

If any unexpected damage or pollution problem occurs, the enterprise is inevitably held responsible. Compensation and fines in these cases are often in excess of the enterprise's ability to pay immediately. Heavy financial losses due to shutdown of operations may also result. Therefore, active investment for the purpose of conserving the natural environment should be understood as being more economical in the long run than the carrying out of mining from the viewpoint of cheaper production alone.

Table 6.--Breakdown of limestone production costs at Garo Quarry.

Item	Pct.	Remarks
VARIABLE COSTS		
Explosives	5.7	ANFO, electric detonators, etc.
Fuel & lubricant	4.8	
Electric power	2.5	Includes private power generation
Stripping & piling	9.8	Special conservation measures
Miscellaneous	0.5	Municipal taxes, etc.
Subtotal	23.3	
FIXED COSTS		
Supply & maintenance	18.8	
Labor	28.6	Includes regular contractors
Depreciation	22.4	
Overhead	6.9	Government taxes, etc.
Subtotal	76.7	
Total	100.0	

CONCLUSION

Environmental management is one of the foremost concerns at Japanese limestone quarries, and is an extremely important technical problem for engineers engaged in mining operations. In this paper, the development and operation of NCC's Garo Quarry has served as a typical example of how an industrial project can be coordinated with the natural environment through the adoption of special measures such as sectional stratified piling in the overburden disposal dump, water control, and revegetation. Examples of revegetation procedures used for quarried areas and final slope at other quarries in Japan are also described. Although introduction of special environmental protection measures does result in increased raw-material production costs, active investment for the purpose of conserving nature should be understood as being more economical in the long run; achievement of low-cost operation, a fundamental goal of private enterprise, cannot be realized without advanced technology. The future of natural resources depends on willingness to pay the price and take the steps necessary to protect the environment.

RECLAMATION PRACTICES AT SELECTED BRAZILIAN MINES (1)

Richard C. Barth, Don D. Williams, and James J. Griffith (2)

Abstract.--Reclamation practices at eight Brazilian mines were evaluated in 1987. Although reclamation laws are often vague and poorly enforced, many mines have excellent reclamation programs implemented by a large staff and good equipment. With climatic conditions favorable for plant growth during most of the year, revegetation can be rapid and plant productivity can be high. Some of the problems observed during this field study included a preoccupation with short-term goals, incomplete soil salvage, slope instability, erosion, compaction, poor site preparation, inadequate fertilization, reliance on introduced species, poor seeding practices, inadequate post-revegetation management, and poorly organized research. Many of these problems have been recognized and are now being addressed.

INTRODUCTION

Mineral production in Brazil during 1985 represented slightly over 4% of the GNP, and this industry is a major factor in the incredible growth of Brazil in recent years (Zineski 1986). Mining in Brazil started nearly 300 years ago with the discovery of gold and precious stones, leaving many degraded landscapes as mute testimony to the impacts of mining. The general public is increasingly aware of the scars left by mining and is becoming critical of the mining industry, especially when mining is conducted near urban areas or in biologically sensitive areas.

Because of this criticism, many mining companies are starting to recognize the significance of the environmental impacts associated with mining. In recent years, various mining companies have attempted to develop reclamation programs. However, a lack of knowledge concerning basic reclamation technology, a lack of trained professionals, insufficient research, and conflicting regulations have hampered the development of cost-effective, environmentally sound reclamation programs.

As a starting point to solving these problems, an evaluation of the current reclamation practices in Brazil was conducted in the spring of 1987. This 6-week evaluation consisted of site visits to eight mining companies located in diverse geographic regions of Brazil and having active reclamation programs. These mining sites included the following: Arafertil (phosphate mine) and CBMM (niobium mine) in Araxa, Minas Gerais; COPELMI (coal) in Butia, Rio Grande do Sul; ALCOA (bauxite) in Pocos de Caldas, Minas Gerais; CVRD (iron) in Serra dos Carajas; CVRD (iron) in Itabira, Minas Gerais; MRN (bauxite) in Porto Trombetas, Para; and MBR (iron), Belo Horizonte, Minas Gerais.

R. Barth, often accompanied by D. Williams or J. Griffith, spent from 1 to 5 days at each mining complex talking with the reclamation personnel and examining the reclamation program in the field. Natural resource, educational, and mining related institutions were also visited. While the mining sites visited can be considered representative of reclamation practices at mines currently engaged in reclamation, it must be noted that a significant percentage of Brazilian (more than 50%) mines are not engaged in reclamation activities at this time.

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THE REGULATORY FRAMEWORK FOR RECLAMATION

Although environmental policy has been emerging in Brazil for over 20 years, reclamation is not specifically mentioned in most environmental acts and resolutions. Thus, these laws have little impact on the practice of mine reclamation, and well-defined and workable environmental regulations have yet to emerge.

One regulation requires that, prior to mining, a permit be obtained. While some environmental issues are evaluated during this permitting process, there are no performance standards or specifications for reclamation. Standards are now emerging, especially for water. A recent resolution requires new mining operations to prepare an environmental impact statement, but few professionals know how to prepare such statements and how to apply them to reclamation. Regulations now under consideration address areas such as inspections, role of the states in environmental regulation, documents specifying environmental control and reclamation planning, soil salvage, and other issues.

Compounding the problems are understaffed regulatory organizations that have little experience or training in reclamation. In addition, their legal jurisdiction over reclamation is either not clear or in conflict with other regulations. Enforcement varies greatly, consequently diluting the impact of these regulations. Therefore, the practice of mine reclamation is, for the most part, motivated by forces other than the legal framework summarized above.

The prime motivating forces for mine reclamation are international financing organizations and pressure from the local community. International financing organizations often require environmental protection and reclamation, and if these activities are substandard, funds can be withheld. Local communities can form an environmental advisory council to the mayor. Although this council is only advisory, its recommendations can be politically important and are often the most significant factor in motivating reclamation.

CHARACTERIZATION OF THE RECLAMATION PROCESS

A characterization of the reclamation practices of the mines visited in this study is presented in Table 1. Following is a discussion of these characteristics.

Corporate Commitment

A corporate commitment to reclamation, starting from the top corporate officers and directed downward within the organization, is essential for successful reclamation. When commitment is lacking, short-term economic gain is often realized at the expense of the environment, and reclamation does not take place. When commitment is given begrudgingly, reclamation proceeds, but not with the speed and quality of results that are evident when management enthusiastically supports reclamation. Of the mines visited during this study, five had excellent corporate support and excellent reclamation programs. The remaining three had only moderate support, and their reclamation programs lacked the quality and dedication of the former group. Companies lacking a corporate commitment to reclamation were not included in this study.

Preplanning

Preplanning is essential to mine reclamation in that it allows identification of problem areas before they arise. Such planning can take many forms, but Brazilian regulations indicate that preplanning involves baseline studies, environmental impact statements, and reclamation plans. However, such documents are not in general use in Brazil, and when such documents are prepared, they are often shelved and forgotten. Only four of the mines visited had scattered baseline information, and just one had comprehensive baseline studies. Environmental impact statements were prepared for only three of the mines visited, and most of the time the impact statement covered only a small portion of the mining complex. Some form of written reclamation plan was found at half of the mines visited, but these plans often lacked the detail necessary for proper implementation.

Reclamation Goals

Short-term reclamation goals identified during this study were dominated by the overwhelming desire to create an immediate visual response. Thus, all mines visited indicated aesthetics to be an important, and usually the most important short-term goal. Erosion control and revegetation were other short-term goals mentioned at all the mines visited. One-half of the mines visited indicated that either fuelwood production or establishment of primary forest was among their short-term goals. One mine indicated that crop production was a short-term goal. Although grazing of reclaimed areas is common in Brazil, only two of the mines indicated that forage production was one of their goals.

Only two of the mining companies studied have looked beyond their short-term goals to determine what their long-term goals should be and how the reclamation process should be oriented to achieve the long-term goals. For many of the mining companies visited, reestablishment of a self-sustaining forest is a logical long-term goal because most of the mining areas were covered by forest prior to mining. In order to reestablish native forest, the short-term goals should be directed at enhancing and accelerating natural succession. However, short-term goals dominated by aesthetic considerations and implemented by use of aggressive introduced species may not support the long-term goal. Most mining companies are content to wait and see what happens in the short term before deciding what to do in the long term. Unfortunately, this

Table 1.--Selected characteristics of eight Brazilian mines engaged in reclamation.

Characteristic	Number of Mines
1. Management Support	
Strong Support	5
Moderate Support	3
2. Preplanning	
Complete Baseline Studies	1
Limited Baseline Studies	4
Environ. Impact Statement	3
Reclamation Plan	4
Reference Areas	3
3. Reclamation Goals--Short Term	
Aesthetics	8
Erosion Control	8
Revegetation	8
Fuelwood Production	4
Primary Forest	4
Forage Production	2
Crops	1
4. Reclamation Goals--Long Term	
Defined Goals	2
Undefined Goals	6
5. Soil Salvage	
Complete Salvage	4
Partial Salvage	2
No Salvage	2
Off-Site Acquisition	3
6. Reclamation Engineering	
Mass Movement Problems	2
Terracing Used	7
Improper Terracing	2
7. Ripping and Topsoiling	
Rip Before Topsoil	2
Uniform Application of Soil	5
Pocket Application of Soil	2
Rip After Topsoiling	3
Off-Site Acquisition of Soil	3
8. Site Preparation	
Soil Analysis	3
Fertilizer Use	8
Fertilizer Deficiencies	6
Rock Phosphate	3
Micronutrient Amendment	3
Micronutrient Deficiencies	3
Limestone	4
Organic Amendments	3
Incorporation of Amendments	8
Rough Surface	3
Pitting	5
Creating Diversity	3
9. Species Selection	
Native Trees Used	7
Introduced Trees Used	7
Native Grasses Used	1
Introduced Grasses Used	8
Woody Legumes Used	7
Herbaceous Legumes Used	2
Wildlife Species Used	2
10. Species Propagation	
Company Nursery	6
Non-Company Nursery	2
Collect Own Seed	6
Sterilized Germinator	5
Special Soil Mix	4
Macronutrients Added	6
Micronutrients Added	2
11. Planting	
Broadcast Seeding	5
Hydroseeding	5
Sodding	3
Stolens	2
Nursery Seedlings	8
Tree Planting:	
In Groves	2
In Small Holes	2
In Large Holes	1
No Preparation	3
Grasses Seeded First	3
12. Management	
Enrichment Planting Needed	4
Enrichment Planting Provided	1
Thinning Needed	4
Thinning Provided	1
Grazing Control Needed	3
Grazing Control Provided	1
Refertilization Needed	5
Refertilization Provided	1
Erosion Control Needed	4
Erosion Control Provided	1
Ant Control Needed	4
Ant Control Provided	4
Fire Control Needed	4
Fire Control Provided	4
Weed Control Needed	4
Weed Control Provided	4
13. Research	
Defined Research Area	2
Organized Research	3

attitude is not conducive to cost-effective and problem-free reclamation.

Soil Salvage

Half of the mines visited removed and salvaged all of the topsoil (or the organically enriched surface material) present in the area to be mined, following removal of large trees and burning at some locations. A portion of the soil resource was removed at two of the mines and the remaining two of the mines did not salvage topsoil. The reason for not salvaging topsoil was either the shallow depth of the topsoil or its excessive rock content. While these reasons were valid in some portions of a given mine, topsoil suitable for salvage was found at all mines, and at three of the mines a significant portion of this valuable resource was not salvaged.

Most Brazilian soils are highly weathered, acid, low in cation exchange capacity, and high in aluminum saturation (Sanchez 1976). In addition, these soils are not the nutrient reservoirs that are found in temperate soils. For example, Jordan (1985) estimated that only 6% of the soils in the Amazon Basin have no major nutrient limitations. However, these soils do contain some plant nutrients, especially micronutrients, that are often essential to the reclamation process. Of greater importance than these nutrients are the microorganisms present in the topsoil. These microorganisms are essential for nutrient cycling, conservation, and absorption by plants (Prance and Lovejoy 1985). Highly dependent and intricate relationships have developed in the tropics between these microorganisms and plants (Jordan 1985; Deshmukh 1986). Although much of this microbial life appears destroyed during topsoil salvage, sufficient numbers appear to survive to be of significant, and often decisive, value in reclamation.

Because of the microbial value of topsoil, direct transfer of topsoil is highly desirable, but only one of the mines visited did this on a routine basis and another mine did it on an occasional basis. The remaining four mines that salvaged topsoil stored the soil from 3 months to over 4 years. The value of stored topsoil rapidly decreases due to nutrient leaching (especially Ca, Mg, K, and nitrate N) (Jordan 1987), and due to the death of microorganisms. Some reclamation personnel are of the opinion that topsoil stored longer than 6 months has lost most of its value for reclamation use.

Reclamation Engineering

During the mining process, overburden is removed and deposited in some manner. This waste deposition creates the basic landscape for subsequent reclamation processes. In many areas of Brazil, mining is conducted on steep slopes, annual precipitation often exceeds 200 cm/year, and prolonged wet periods are common. Thus, stability of the waste cannot be taken for granted and thorough engineering is required to ensure slope stability. Such engineering may not take place, and at two of the mines visited, mass movement of mining waste was a major problem; it was a potential problem at several other mines.

Controlled overburden deposition appears to be the best method to stabilize large waste deposits in steep terrain. This generally involves as drain blanket at the base of the waste dump, internal drainage, a rock-stabilized base tied into bedrock, benches that drain both inward and to the side of the deposit, stabilized drainage chutes along the sides of the deposit, compacted fill, and in some cases a compacted clay cap on the benches. All mines operating in steep terrain visited during this study had controlled overburden deposition in at least one of their waste disposal areas, but only one of these mines deposited all of their overburden in a controlled manner. The cost of controlled overburden deposition was estimated at 12% more than uncontrolled deposition; thus, this basic reclamation requirement is not expensive.

Terracing is another method of increasing stability and enhancing reclamation. At seven of the mines visited terracing was used to some extent. Terrace widths averaged 10 m and the vertical distance between terraces also averaged 10 m. Unfortunately, at two of the mines using terracing, the terraces were improperly designed and provided little water control and slope stability. Water intercepted by the terrace must be drained along the terrace and down drainage structures at the edge of the terraced deposit. Without this drainage, the terrace quickly fills with water during intense precipitation and overflows.

Ripping and Topsoiling

In most areas of Brazil, the overburden is high in clay and prone to compaction during backfilling. Although ripping is not possible in all locations (due to the presence of clay caps, drainage systems, or steep slopes), overburden ripping was possible at six of the mines visited, but only two of the mines engaged in this practice. Reclamation efforts at the remaining mines were often hampered by compacted overburden.

Topsoil was applied in a uniform manner at five of the mines. The depth of topsoil applied ranged from 3 to 50 cm and averaged 20 cm. At two of the mines, topsoil was applied only in pockets dug for tree planting. Following topsoil application, three of the mines ripped, disked, or harrowed to relieve compaction and to incorporate amendments. At the mines where this was not practiced, revegetation efforts were often hampered by compacted soil.

At three of the mines visited, topsoil availability was insufficient to meet perceived reclamation needs. To overcome this problem, the mines obtained topsoil from undisturbed areas, usually from farmers willing to sell topsoil from their pastures. This practice should be discouraged. Not only is it costly, but creating a disturbance in one area to solve a disturbance in another gains little as far as the environment is concerned. In most cases where topsoil appears insufficient for reclamation, the overburden can likely be modified (by application of fertilizers and incorporation of organic matter) to serve as an acceptable growth medium.

Site Preparation

Basic to revegetation is an understanding of the chemical traits of the growth medium and how these traits affect plant growth. However, only three of the mines visited analyzed the growth medium, and in most cases the analyses were incomplete and of little use. As a result, there was little scientific basis for the application of amendments.

At all of the mines visited, fertilizer was applied, generally a NPK fertilizer, but there was no consistency in nutrient composition or application rate among the mines and often at the same mine. Because of the lack of a quantitative approach to fertilizer application, nutrient deficiencies were common and six of the mines visited had at least a portion of the revegetated area deficient in macronutrients, particularly nitrogen.

Rock phosphate was used at three of the mines, especially in conjunction with tree planting. Rock phosphate is slowly soluble and is used to provide a long-term supply of phosphorus; however, the effectiveness of this practice is not known.

Although micronutrients are often deficient in the highly weathered soils in Brazil, only two of the mines visited analyzed the growth medium for micronutrients. However, three of the mines applied B, Zn, or a micronutrient mix to the growth medium. In at least three of the mines visited, vegetative growth appeared restricted due to inadequate micronutrients, especially B.

Another common amendment was limestone and four of the mines applied this amendment. Soil pH was often in the 4.0 to 5.0 range, and sufficient limestone was applied to increase the pH to the 6.0 to 6.5 range. In one case, ash from a paper mill was being used on an experimental basis as a neutralizing agent.

Organic amendments were also important, especially for Brazilian soils which typically have a low organic matter content. However, only three of the mines visited used organic amendments. Organic amendments such as manure, composted garbage, grass and tree clippings, sewage sludge, sugar cane pulp, rice hulls, waste from paper pulping, and sawdust are readily available in many parts of Brazil. Unfortunately, there seems to be a general reluctance to handle waste products in Brazil, thus depriving reclamation of a very beneficial amendment.

Amendment incorporation depth is often shallow, usually 15 cm. Deeper incorporation of amendments would likely be beneficial, especially if amendment application rates were increased proportionally.

Another part of site preparation was creating a rough surface that would hold seeds and restrict erosion. At three of the mines visited, this type of surface was created by ripping or disking the surface. Pitting was also a common method to produce a rough surface, especially on slopes. The pits were made by hand, usually using some type of hoe, and were made in a random manner or oriented along the contour. While these pits can interrupt surface flow and are of some value in erosion control, their primary benefit is in providing a flat area, generally from 10 to 20 sq cm, where seeds can reside during germination. Pitting was used at five of the mines visited.

Site preparation also involves creating landscape diversity, and this process is usually started during backfilling. Creating such diversity was taking place at three of the mines visited. Techniques included the use of boulders, creation of ponds, and species manipulation.

Species Selection

The selection of species used in revegetation has been substantially influenced by a preoccupation with short-term goals and the desire to produce a landscape that has immediate visual appeal. This has led to the use of aggressive, fast growing introduced grasses. Roughly estimated, 40% of the rehabilitated areas in Brazil are dominated by a single species of introduced grass. This species, grease grass (Melinis minutiflora), also excludes other species and is highly flammable. For these and other reasons, two of the mines that planted this species in the past no longer plant grease grass, and at one mine this species was being removed.

Woody species used in revegetation are dominated by native trees. This is not surprising when one considers that within or adjacent to the mining sites involved in this study, the number of native woody species ranged from 90 to over 1000. Percentage of native trees used in revegetation ranged as high as 100% and averaged 70% for the mines visited. Only one mine was not planting native trees at the present time. Fast growing introduced trees, particularly eucalyptus, were also important, especially for fuel production, and seven of the mines planted introduced trees. Two of the visited mines planted tree species specifically for wildlife use.

In contrast to the use of native trees, only one of the eight mining sites used native grasses, and all of the mining sites used introduced grasses. This reliance on introduced grasses should not imply a shortage of native grasses in Brazil. A recent botanical study at one of the mines identified 67 species of native grasses in the mining area, and it was estimated that over 200 species could be found in adjacent areas. The lack of seed availability, a lack of knowledge concerning species suitability, and germination problems have discouraged the use of native grasses.

Because of the nutrient-poor soils, legumes are important in species selection. Recognizing this, seven of the mines visited were planting an average of 24 species of woody legumes. Unfortunately, only two of the mines were planting herbaceous legumes at this time.

Longevity is also an important consideration in species selection. Some of the best growing and most widely planted trees used in revegetation have a life span of only 20 years. Because of the preoccupation with short-term reclamation goals, the question of what will happen when these trees start to die has not been addressed.

Species Propagation

Species propagation refers to the raising of wood species in a nursery for subsequent planting in areas being revegetated. Of the mines visited, six produced their own seedlings in a company operated nursery, and the remaining two obtained seedlings from private nurseries. Annual seedling production averaged 60,000, with two of the nurseries producing more than 80,000 seedlings.

Many aspects of seedling production have become standardized. All of the nurseries collect their own seed and germinate the seeds in shaded areas. A sterilized medium is used for germination at five of the nurseries, and the remaining nurseries will likely use this method to avoid mold and fungus problems during seed germination. Once germinated, the seedlings are generally transferred to soil-filled plastic bags. At four of the nurseries, a special soil mixture was used to assure proper seedling nutrition, proper microbial activity, and ease of handling. This special mixture used topsoil amended with such materials as manure, worm mulch, sawdust, plant litter, and the surface 2 cm of forest soil. All nurseries applied NPK to the soil mix, and two added a micronutrient fertilizer. Seedlings generally were field planted 6 months after germination; height at the time of planting was approximately 50 cm.

Most nurseries visited were very well managed and seedling quality was high. Perhaps the most serious problem observed was a reluctance to discard seedlings that were growing poorly and that would probably not survive field planting regardless of how long they stayed in the nursery. In one nursery, a micronutrient deficiency appeared to be restricting seedling growth.

Planting

Planting by Seed

All of the mines visited planted grasses by seed, and one of the mines planted shrubs and trees by seed. Broadcast seeding was practiced at five of the mines; hydroseeding was likewise practiced at five of the mines. There appeared to be no inherent advantage of one seeding method over the other, and there were no observable differences in revegetation success. One company expressed the opinion that both seeding methods produced the same results, except that broadcast seeding was easier because there were fewer things to break down. Seeding takes place throughout the wet season and establishment is usually good except when a dry period follows seed germination.

A grass cover can also be obtained by vegetative means, and three of the mines visited have used sod in some areas and two have used stolens. These vegetative techniques are generally limited to highly visible and sensitive areas.

Planting by Seedling

Methods used in planting tree seedlings varied from mine to mine. At two of the mines visited, trees (about 30 cm tall) were planted in groves that resulted from ripping the surface. At two other mines, slightly larger trees were used (about 50 cm tall) and planting consisted of (1) excavating small holes (less then 0.5 cu m), (2) mixing soil, fertilizer, limestone, and organic matter with the substrate, (3) filling the hole, and (4) planting the seedling in this enriched pocket. At another location the same technique was used, except that the excavation approached 1 cu m and tree height at the time of planting was approximately 1 m. At the remaining three of the mines, trees from 30 cm to over 1 m tall were planted in soil or overburden without any special treatment other than fertilizer. One mine tried using an auger to make the planting holes, but this technique compacted the soil and reduced seedling survival.

Tree spacing depended on the species involved and the intended use of the area. Eucalyptus (Eucalyptus spp.) plantations had the closest spacing while native trees had the widest spacing. The species sequence in planting was dependent on the objective. When a strong visual response was desired, seedlings of the same species were usually planted in small groups, often with reduced spacing within the group and large spacing between groups of different species. When native forest was the objective, the species sequence was usually random.

At most mining locations visited, grasses and trees were planted at the same time if a mixed community was the goal. At three of the mines, grasses were seeded before the trees were planted. This sequence gave an immediate visual response, but resulted in severe competition between the grasses and trees.

Management

Once an area has been planted and a pleasing green landscape created, reclamation is often considered complete. However, some management is required to ensure that reclamation is self-sustaining. All mines visited found it very difficult to provide this management.

Following revegetation with grasses and/or trees that provide the desired visual impact, an enrichment planting was often planned where more permanent vegetation was planted. Such enrichment plantings were part of the reclamation strategy at four of the mines visited, but only one of the mines had started this process. At four of the mines visited, thinning was necessary, but this process had taken place at only one of the mines. Revegetated areas can tolerate grazing if the proper species are planted and if grazing is managed; at three of the mines visited grazing was allowed. However, at two of these mines, this grazing was not controlled and often occurred immediately after planting. This resulted in severe damage to the trees and grasses in localized areas. Nutrient deficient vegetation was observed at five of the mines visited, but only one of the mines had a refertilization program. Accelerated erosion of reclaimed areas was a problem at four of the mines. Such problems were usually attacked with a hydroseeder with the idea that a green slope could not possibly erode. A permanent solution to the problem would likely involve hand excavation to reestablish proper drainage followed by hand recontouring and revegetation. Only one of the mines visited provided this type of follow-up erosion control. Unnecessary use of bulldozers appeared to be a problem at many mines. Probably the best solution to this problem is a systematic effort to sensitize equipment operators about reclamation.

Some management needs were receiving proper attention. Fire, weed, and ant control were needed at four of the mines visited, and this type of management was generally provided.

Research

Research was recognized as part of the reclamation process, and research programs of some type were found at all mines visited. However, only two of the mines visited had well-defined research areas and only three of the mines had a well organized research program. Some of the more serious problems encountered included a lack of control areas, lack of adequate replication, poor records, lack of statistically valid experiment designs, uncontrolled variation, and inadequate data collection. Any one of these problems can invalidate the research effort or give erroneous results. Therefore, some of the research now taking place will be of little value to the company and to colleagues faced with similar problems.

SUMMARY

Although reclamation following mining in Brazil is a relatively new concept and programs are just in their infancy, all of the mines visited during this study are doing a commendable job at reclamation and the results obtained thus far are impressive. Reclamation personnel are taking advantage of the experience and research in other countries, and are quickly learning both the art and practice of reclamation. Given the warm climate and abundant rainfall in Brazil, reclamation is often rapid and large areas of mined lands have been transformed from ugly scars to green hillsides within the last few years.

As expected, there are problems in some areas of the reclamation process. Perhaps one of the more serious problems is a preoccupation with short-term goals that seek little more than to establish a pleasing landscape. Technical problems include incomplete soil salvage, slope instability, accelerated erosion, poor site preparation, inadequate fertilization, over use of introduced species, poor seeding practices, inadequate post-reclamation management, and poor research techniques. Most reclamation personnel are aware of these short comings and are working hard at correcting the problems.

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RECENT DEVELOPMENTS IN THE USE OF MINING AND OTHER WASTES IN LAND RECLAMATION IN THE UNITED KINGDOM[1]

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Abstract.--Subsequent to recent reorganization, British Coal Corporation's Minestone Services have embarked on a considerable research programme directed towards the use of colliery waste and other problematic waste products in the reclamation of derelict land. In this manner a dual environmental benefit is gained by, on the one hand clearing up abandoned pit heaps and on the other using the material to clear up other derelict areas, whilst at the same time saving other strategic bulk-fill materials which might otherwise have been used. Until recently use of minestone as a soil in land reclamation to lowgrade agriculture has been limited because the material is low in plant growth nutrients. In the past, large and expensive amounts of fertilizers and topsoil were used to achieve successful growth which often required later further applications to prevent regression. Now, with the use of colliery waste, which physically forms a good basis for soil, and other waste materials such as sewage sludge, pelletized refuse, and flue gas desulphurization end products from coal-fired power stations, it is hoped that restoration can be made very cheap and effective. Because these materials also pose acute disposal problems, their combined use as soilmaking material can often be achieved for haulage costs alone. Where amenity use restoration is concerned it is often desirable from a planning regulation point of view to restore sites to acceptable and aesthetic levels using trees. The recent developments in biotechnical engineering have advanced the possibility for much improved success rates in tree planting using mycorrhizal inoculants. This method is now being researched to perfect transplantation of the more sought after trees such as oak, beech, and ash. A second area of research using colliery wastes and other waste materials is in restoring mine sites to amenity lakes or wetland. Wet restoration has always been a problem for mining companies where a high ground water table exists and there is the possibility of acid mine water in the restored lake. Recent developments in the use of sewage sludge through the process of eutrophication have made it possible to

not only restore mine sites to acceptable lake amenity use, but also to use problematic colliery waste as bulk fill to prepare the geometry of the lakebed in other mines and quarries. With the additional use of wetland environments to create an environmental 'niche' for wildlife many old mining sites can now be confidently restored very cheaply to publicly acceptable use.

INTRODUCTION

Since 1987 is 'European Year of the Environment' (EYE), it is significant that a number of new laws and regulations have been introduced by the Department of the Environment in the United Kingdom that speicifically relate to the disposal of mining waste (Dept. of Environment 1987). As recently as 1984 the Survey of Derelict Land in England showed that there were over 45,000 ha of derelict land which were classified as justifying restoration. Of this, by far the largest proportion (29%) was associated with coal mining. There were also about 40,000 ha of derelict land in inner city environments which also required urgent attention and have given rise to the formation of Urban Development Corporations in the worst areas of urban decay.

During the last decade British Coal has undertaken considerable research work into methods of assisting in the removal of these environmental eyesores. Many of the streams and lakes in coal mining areas suffered from the effects of acid mine drainage and only in recent years have steps been taken to alleviate this problem in order to meet the strict controls under the Control of Pollution (Rivers) Act 1974 The success met with in this endeavour and in cleaning up other forms of river pollution has resulted in a recent survey (Water Research Centre 1987) showing that the United Kingdom now has the cleanest river system in Europe (table 1).

Although as table 1 testifies, much has been done in the United Kingdom to purify rivers and lakes, there are still many areas of dereliction caused by industries that have long since been abandoned which require reclamation.

Table 1.--Pollution in European Rivers (Water Research Centre 1987).

Country and date of survey	Proportion of river length in UK quality classes (%)				
	1A	1B	2	3	4
Belgium (75-9)	35	21	17	16	11
Denmark (86) (est)	(----80---)		(---20----)		
France (81)	8	26	60		6
West Germany (85)	6.5	38	40	14	1.5
Greece (est)	20	40	20	15	5
Ireland (80/1)	(----84---)		(---14--)		(-2-)
Italy (no survey)	-	-	-	-	-
Luxembourg (84)	47	25	13	11	4
Netherlands (78)	12	65	18	4	1
UK:					
Eng & Wales (80)	36	33	21	8	2
Scotland (80)	95		4	0.5	0.5
N Ireland (85)	15	69	11	5	0
EEC Overall	14	25	35	22	4

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[1] Paper presented at the 1988 Mine Drainage and Surface Mine Reclamation Conference sponsored by the American Society for Surface Mining and Reclamation and the U.S. Department of the Interior (Bureau of Mines and Office of Surface Mining Reclamation and Enforcement), April 17-22, 1988, Pittsburgh, PA. The views expressed in this paper are those of the author and do not necessarily represent those of British Coal Minestone Services.

There are over 1,000 Million tonnes of coal mining waste disposed of above ground level in the United Kingdom, the legacy of over 500 years of continuous mining. Modern high-production long-wall coal mining methods are also extremely wasteful, and this figure is being added to by about 60 Million tonnes every year.

There is therefore considerable logic in not only restoring existing areas of coal mining wastes, but also in using these considerable reserves of material as bulk fill in the restoration of other derelict areas. One of the major problems in the past has been difficulty in using the top layer for growing plants in agricultural or amenity use. This often necessitated the use of considerable amounts of expensive topsoil, chemicals, and fertilizer.

Where a good cover of grass or trees is required on land reclaimed with colliery waste, then the use of variable mixes of other waste products such as sewage sludge, flue gas desulphurization end-products, and pelletized refuse from urban incinerators can have a beneficial effect.

More than often local government planning regulations insist on the planting of trees to increase the aesthetic value of the restoration. The success rate of transplanted nursery trees can be greatly enhanced through the use of biotechnically engineered mycorrhizal inoculants of fungi on the roots during transplantation.

Many areas of dereliction are in tracts of land which are below the water table. This is especially true of abandoned surface mines and quarries. In order to restore these, bulk fill in the form of minestone can be used. However, if it is used, there remains the problem of potentially acid waters occurring in the subsequent lake or wetland environment. The use of selected sewage sludge in such environments has recently proved to be effective in maintaining a neutral pH. In this way the mines and quarries can be handed over as recreational areas for water sports or as wildlife reserves for waterfowl and other endangered species.

The prospect of such restoration often meets with considerable sympathy with government bodies when planning permission is sought for the original mining venture.

VEGETATION GROWTH ON COLLIERY AND OTHER WASTES

In the past in order to achieve good vegetation on colliery waste considerable amounts of chemicals and fertilizer had to be used to reduce the acidity and to provide nutrients for the plants. In order to create the necessary conditions for plant root growth the surface must be left uncompacted and open for moisture and air to penetrate. These, of course, are the very conditions in which acidity is generated by the breakdown of iron pyrites (FeS_2) which can vary between 0.5% and 7.0% in British spoils. One gramme of sulphur will produce 3.06 g of sulphuric acid in the overall reaction which is accelerated in the presence of certain bacteria and is also exothermic. The resultant high temperatures also do little to promote moisture retention and root growth.

Using topsoil to cover the colliery waste is not practical because good topsoil is a rare commodity in many of the coal mining areas as a result of the downturn in large civil engineering projects during recent years. As a result of this, it is therefore very expensive, at around £3000/ha. It is thus of considerable benefit to be able to provide a growing medium without recourse to topsoil or large amounts of chemicals. Chemicals also leach out of the spoil very quickly, and repeated doses are required for many years in order to prevent regression of growth. Many restoration projects in the past have suffered this way and there is a need for a one-off treatment during restoration which will last until the plants have become established and self generating. Some other waste products offer this potential and often have disposal problems of their own which mean they are cheap and plentiful.

Sewage Sludge

A great deal of research is taking place into the use of sewage sludge in reclamation using colliery spoil. (Hall et al. 1986, Hall and Vigerust 1983). The main benefits of sewage sludge are that it gives up its nutrients slowly and has high moisture retention properties. It therefore has the advantage over chemicals in that it will allow a well-established vegetation to form without regression. Its main use is in the formation of poor grazing and amenity use land. The most important factor concerning its use is that the sewage sludge must be selected carefully. It has gained an unfortunate reputation with the public and some local authorities as a result of some cases where highly toxic forms of sewage have been used in the past. The improvements in sewage treatment in recent years and more restrictive legislation as to its use have now meant that it is used quite frequently in pit heap restoration and in final restoration in surface mining.

In some areas the sludge cannot be used as it contains heavy metals in excess of the Department of Environment (1984) guidelines on the disposal of sewage (table 2).

Several trials have now been undertaken by the Water Research Centre, various local water authorities, the Ministry of Agriculture, and British Coal and the results to date are extremely encouraging. It is envisaged that it will be particularly useful in areas where topsoil is naturally scarce and in areas of industrial and urban dereliction.

Table 2.--Dept. of Environment guidelines for some toxic metal 'trigger' concentrations (in mg/kg).

Zootoxic Metals	Agricultural	Amenity
As	10	40
Cd	3	15
Cr	600	1000
Pb	500	2000
Mg	1	20
Sc	3	6

Use of sewage sludge in reclamation has an added benefit in that sewage sludge disposal is a major problem in a densely populated country such as the United Kingdom. In England about 30% is disposed of at sea and in some parts of the U.K., notably Scotland, as much as 78% is disposed of in this way. It is doubtful whether legislation, either local or by the European Parliament, will allow this to continue ad infinitum, and stricter controls are inevitable. At present only 7% is used in land reclamation, the remainder being used for agricultural purposes. There is much potential therefore for its use in land reclamation.

Biotechnical Engineering

Trees are probably the most important facet of any restoration and are certainly the form of vegetation cover which Planning Authorities would hope to see in any reclamation project. Trees which have been seen to thrive naturally on even acidic spoils have been found to have a symbiotic fungal growth on their roots. These ectomycorrhizae form a sheath which protects the tree from the agressive environment, and fungal shoots (hyphae) extend the root system in search of the scarce nutrients in such a soil. Through advances in biotechnical engineering it is now practical to take a culture of the specific fungus appropriate to each species of tree and create a 'root dip' for use when the tree is transplanted from the nursery onto the reclaimed land. The success rate for tree growth is greatly improved at a cost of only around three pence per tree. In some recent experiments carried out for British Coal by Biotal Ltd. the success rate for Sitka Spruce using a mycorrhizal inoculant of Laccaria laccata gave shoot lengths of 25 cm after 36 weeks compared to untreated specimens of only 10 cm during the same period.

Biotechnical Engineering can also be used to develop plants which can thrive in aggressive conditions. It is the intention of British Coal to promote the use of colliery waste in marine environments for such schemes as tidal barrages and dockland restoration. These areas are susceptible to salt spray, and it is hoped that biotechnical research will find plants that can withstand both the salt and acid soil environment.

Many of these applications are on steep slopes and the selection of certain plants such as the Black Locust tree, which has an 8-m-deep root system, can be used as a natural and more aesthetic form of slope stabilization than normal civil engineering methods. The roots of this tree act as natural soil anchorage systems and have a tensile strength of about 1,200 kg/cm^2 (Waldron 1977). It is hoped that these more natural forms of stabilization will be used more frequently in road and rail embankments, other slope construction, and even in surface mine design.

WET RESTORATION USING COLLIERY WASTE

Many derelict land sites, surface mines, and quarries are in areas where there is a naturally high ground water table at or near the surface (Norton 1983). Quarries which are excavated for bulk minerals are often abandoned with a large void which cannot, for one reason or another, be reclaimed with any locally available material or cannot be used for refuse disposal because of the high water table. However, the site can be reclaimed to a lake or wetland environment by partially filling the void using colliery waste which is in abundant supply and will usually only incur a haulage cost, as opposed to other bulk fill materials which have to be excavated from green field sites.

In the past mining waste has caused problems with acid mine water resulting from the oxidation of the ubiquitous iron pyrites. Until recently the only cure was to treat the water with lime or caustic soda. This was not only expensive and environmentally problematic, but also required frequent subsequent doses to prevent acidic regression. At one mine site about 50 tonnes of lime per week was necessary to treat an outflow of 160 L/sec with a pH of less than 4. The resultant annual cost was in the region of £1 Million. Similar expensive methods have also been used in the treatment of acid lakes caused by sulphuric air pollution from coal-fired power stations.

The use of sewage sludge as an alternative treatment was first researched in the United Kingdom by the Freshwater Biological Association in conjunction with British Industrial Sands (Davison 1986, Needham 1986) at a sand quarry with a high water table which resulted in a lake with a pH of 3. Although the acidity was caused by the presence of iron-rich minerals in a bed of sand below the restored quarry floor, the principle of the remedial measures is similar to that proposed at sites using colliery waste.

Minestone is a very suitable material for this purpose as its removal from existing pit heaps improves the environment and releases the land for development. The restoration of a site to amenity lake or wetland involves four distinct stages: backfilling, inundation, neutralization, and eutrophication.

It is essential that the backfilling creates a suitable geometry for the proposed lakebed with maximum angles of 14° and as much of the area horizontal as possible. Simple compaction with sheeps foot or vibrating rollers is then necessary to provide an impermeable top layer. Normal colliery waste can provide permeabilities as low as 10^{-8} cm/sec and is used to prevent the ingress of further acidic water.

The next stage is inundation, where all the dewatering mine pumps are switched off and the lake filled as quickly as possible. The diversion of other unpolluted surface waters into the lake can be used to speed up the process and also to dilute the acidity.

Once the lake is full then the remaining acidity in the water can be reduced further with a one-off small addition of lime or preferably caustic soda if, as is usual, the water is high in calcium salts. About 100 tonnes of caustic soda/10 million m^3 of water is all that is required if the pH is around 3.5.

In the final stage sewage sludge is added in order to provide organic material on which anaerobic bacteria feed and convert sulphates in the polluted water to sulphides by a process known as eutrophication in a reducing environment. It is essential of course that the lower levels of the water are still and any potential turbidity caused by flood conditions can be prevented by the construction of a weir system upstream of the lake. The deepest part of the lake is therefore kept anoxic, allowing the bacteria to thrive. Eventually the lakebed is composed of organic sediment and layers of harmless metallic sulphides as occur quite naturally in deep stagnant lakes (Love 1967). One of the main criticisms of this method is that some sewage contains pathogen and toxic metals. It is therefore important that the correct type is used. Modern methods of sewage treatment can now provide the necessary material. In addition, the fact that the water is acid usually eliminates any pathogens that remain.

The construction of a wetland or bog environment on the site can be used to treat the acidity that may be generated from colliery spoil outside the catchment of the lake. These wetlands have the added benefit of providing an ecological 'niche' for wildlife which creates much public and planning approval and also prevents pollution of downstream watercourses.

CONCLUSIONS

A combination of any of the above methods of restoration have now given an added impetus to the potential use of colliery waste in the reclamation of derelict land and quarries and its use in marine and land-based structures. The combined use of waste materials and the modern science of biotechnical engineering can do much to improve the environment in coal mining areas. The dual benefit of simultaneously removing abandoned pit heaps and using the material for reclaiming other areas of dereliction cannot now be ignored, and with local and national government support it is hoped that much more use can be made of this readily available and increasingly valuable source of bulk fill material.

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ACID WASTE ROCK MANAGEMENT AT CANADIAN BASE METAL MINES[1]

Alan V. Bell, P.Eng.[2]

Abstract.--An inventory of acid waste rock management methods at Canadian base metal mines was undertaken with a view to defining the current state of the art and areas of future research. The status of alternative methods such as insitu neutralization, underwater disposal, sealing techniques, bactericides, segregation, and treatment are reviewed. It is concluded that preventative management methods are in their infancy and several areas of research are recommended with emphasis on cellular design of waste dumps, various types of cover, and underwater disposal.

INTRODUCTION

In 1983, the Canadian base metal mining industry and Federal government initiated a joint program of applied research directed at determining solutions to the long-term management of reactive acid tailings. The program is referred to as the Reactive Acid Tailings (RATS) program and is scheduled for completion in 1992.

During the fall of 1986, it was decided to broaden the scope of the RATS Program to include acid waste rock (AWR). A study was therefore initiated to prepare an inventory of acid waste rock at Canadian base metal mines, to define existing and potential acid waste rock management methods, and to define research and development requirements that might be integrated into the RATS program. This paper is based on the findings of the Acid Waste Rock Study (Nolan, Davis & Associates Ltd., 1987).

DESCRIPTION OF STUDY

Nature of Acid Waste Rock

Base metal mining operations in Canada employ both open-pit and underground mining methods. In sulphidic areas, both can result in acid-generating waste rock. For underground mines, the volume represents primarily development rock and is therefore significantly less than that for most open-pit operations where the ratio of waste to mill feed is typically in the order of 2 to 2.5. The generation of waste rock at open-pit mines is a continuing function of the mining operation, meaning that waste disposal areas must remain active throughout the life of the mine. The characteristics of base metal mine waste rock are highly site specific, but it tends to be less friable than most coal wastes, thus resulting in waste dumps that are very permeable to air and water unless preventative measures are applied.

Occurrence of Acid Waste Rock in Canada

The approximate distribution of acid waste rock at base metal mines in Canada is shown in table 1. It is important to appreciate that the tonnage figures given are approximate and that they represent only base metal properties. Acid waste rock is also associated with a number of other minerals in Canada including gold, uranium, and coal which were not included in the study.

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[1] Paper presented at the 1988 Mine Drainage and Surface Mine Reclamation Conference sponsored by the American Society for Surface Mining and Reclamation and the U.S. Department of the Interior (Bureau of Mines and Office of Surface Mining Reclamation and Enforcement), April 17-22, 1988, Pittsburgh, PA.

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Table 1.--Distribution of AWR at Canadian base metal mines.

Province/Territory	Number of Properties with AWR	Approx. Tonnes
British Columbia	9	250,000,000
Alberta	0	---
Saskatchewan	0	---
Manitoba	9	100,000
Ontario	16	50,000,000
Quebec	9	250,000
New Brunswick	6	4,000,000
Nova Scotia	0	---
Prince Edward Island	0	---
Newfoundland & Labrador	4	100,000
Yukon	2	10,000,000
Northwest Territories	1	500,000
	TOTAL: 56	315,000,000

Acid waste rock management is regarded as an important environmental issue in British Columbia and New Brunswick. In other regions containing reactive mine wastes, the management of acid-generating tailings is regarded as a more important priority within the base metal mining sector.

The technology to collect and treat contaminated leachate from AWR piles is well established and offsite contamination was found to be a problem only at abandoned properties where these practices are not maintained (10 of the 56 properties identified).

The inventory also showed that the application of preventative management methods for AWR is in its infancy in Canada, as elsewhere, and that there is in fact no proven method of AWR management for which back-up leachate collection and treatment is not required in most circumstances, with the possible exception of underwater disposal.

Acid Generation in Waste Piles

Factors influencing acid generation in pyritic waste dumps include pH (fig. 1); the amount of oxygen at the pyrite surface; the morphology of the sulphide minerals present; temperature (Morth 1965); the rate at which reaction products are transported away from the reaction site (Knapp 1987); the buffering capacity of the waste rock at the reaction site; humidity; and the availability of carbon dioxide, nutrients, and trace elements essential to microorganism growth.

John (1987) reports the most critical factor in the oxidation of pyrite to be the availability of oxygen and that the oxygen concentration required for the support of bacterially mediated oxidation is 0.5 mg/L (1.6 mol fraction percent). Nicholson (1984) shows that the relationship between oxidation rate and oxygen concentration is nonlinear and attributes this to complex adsorption-desorption mechanisms at the reaction site.

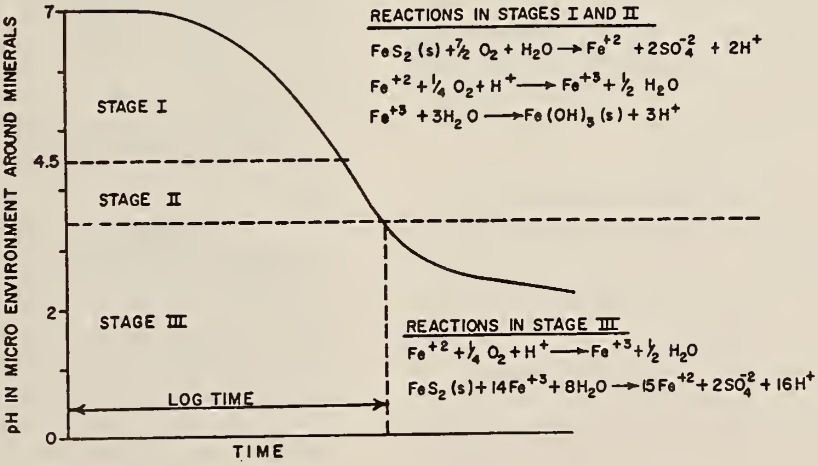

FIGURE 1 - STAGES IN THE FORMATION OF ACID MINE DRAINAGE
AFTER FERGUSON & ERICKSON, 1987

An insight into the factors influencing the generation of pollutants in waste rock dumps can be obtained by reviewing the literature on heap leaching for beneficiation purposes. The efficiency with which air is drawn into a heap leach pile is recognized as a key parameter (Cathles and Apps 1975). Good leachate qualities for beneficiation are dependent on maintaining air as the main source of oxidation rather than dissolved oxygen in the leach solution; this is a factor which should be kept in mind when trying to minimize waste dump contaminate leaching. Cathles and Schlitt (1980) conclude from the development of a two-dimensional dump leach model that beneficiation leaching of copper from low-grade dumps is fastest for dumps of 15 - 30 m height, that permeability of the dump is very important, and that leaching is facilitated if the leach solutions are preferentially supplied to the hot, near-edge portions of the dump.

Thus, one would conclude from these findings that to minimize leachate production in acid waste rock piles, one should reduce the permeability of the dump to air, try to prevent the exothermic oxidation reaction from significantly raising the dump temperature, minimize leachate transport, and prevent the ingress of seepage to the outer portions of the dump.

U.S. Experience with Acid Coal Spoils

Most of the literature specifically addressing the issue of acid waste rock management has developed as a result of surface coal mine operations in the Eastern United States. Although the basic objectives are the same, the practical considerations in relation to materials handling are quite different at a strip mining operation from those of a hard-rock open-pit situation common to base metal mining.

Several waste management principles that are applicable to hard-rock operations are identified in the literature pertaining to coal wastes. Cathles (1982), for example, compares the management of coal spoil piles to beneficiation leaching and emphasizes the importance of reclaiming pyritic spoils as soon as possible after mining in order to limit the oxidation of the spoil to the limited potential of "buried air". He recommends the following three steps to reduce the amount of acid generated:

1. Bury and cover the spoil as soon as possible after mining.
2. Compact spoil piles to eliminate air convection and reduce oxygen diffusion into the pile.
3. Consider the addition of bactericides to the pile.

Cathles, in the same reference, also states that while the burial of coal waste below the water table is not always possible, "a few feet of water will reduce the pyrite oxidation rate effectively to zero".

Erickson (1987) confirms that the current practice for the disposal of coal spoils in the United States now involves placement in optimized sites with compaction of the material during placement, followed by covering and revegetation.

Infanger and Hood (1980) report that the sequence in which overburden materials are placed in relation to acid coal spoils has a marked effect on leachate quality. In general, the more alkaline materials should be placed above the acid-producing material, and if possible, the pyrite layer should also be placed below the water table.

Many coal mine spoils in the Appalachian region of the United States produce low amounts of acidity (less than 30 mg $CaCO_3$/L per 100 g sample). In such cases, it has been demonstrated that mixing in the equivalent of a 0.3-m layer of limestone will inhibit acid production in the top 3 m of spoil, thus effectively arresting the leachate problem (Williams et al. 1982). Other researchers on acid coal spoils indicate that the placement of soil covers in excess of 0.6 m provides a preferable treatment technique to the use of ameliorants such as lime, limestone, or sewage sludge (Apel 1982).

Revegetation can provide an aesthetically pleasing cover to reclaimed spoil areas and will stabilize the surface from erosion. However, it is recognized by a number of authors (e.g., Farmer and Richardson 1981) that revegetation in itself will not curtail acid generation in spoil piles. This finding is supported by Veldhuizen et al. (1987) in relation to revegetation trials on acid-generating base metal tailings. They conclude "direct vegetation of reactive tailings does not restrict pyrite oxidation nor does it limit water infiltration to significantly reduce·water flow from the impoundment".

Carruccio and Geidel (1987) report the use of alkaline trenches as a successful approach to shifting high acid leachate spoil systems towards more alkaline regimes.

Hard Waste Rock Management

There is very little literature on the management of reactive hard rock wastes typical of base metal mines in Canada. Eger and Lapakko (1981) report a series of leaching tests undertaken on experimental stockpiles containing metal sulphide wastes at the Minnamar site in northeastern Minnesota. They concluded that covers consisting of 18 cm of topsoil and 30 cm of sandy till over 28 cm of coarse sand were more effective in reducing the quality and quantity of leachate than a cover consisting only of 29 cm of coarse sand.

Work undertaken on the covering of two pyritic waste rock dumps at the Rum Jungle Mine in the Northern Territory of Australia has been reported by several authors. Harries and Ritchie (1986) describe the reclamation measures applied to the two dumps which contain approximately 4 x 10^6 tonnes and 0.8 x 10^6 tonnes of material. Essentially, the sides of the dumps were worked to give a maximum slope of 1 vertical to 3 horizontal with a berm half way down the slope. Engineered drop structures were provided to take surface water from the berm to the base of the dump. The dump was then covered with 3 layers of material:

-on the top:

225 mm compacted clay followed by 253 mm

of clayey sand and a minimum of 150 mm of gravelly clayey sand

-on the sides:

300 mm compacted clay followed by 300 mm clayey sand and 150 mm broken rock

Vegetation was established on the surface to provide protection and improve the aesthetics of the dump.

The trial showed that the cover effectively stopped air transport through the dump both by diffusion and thermal convection, thereby lowering oxidation rates within the dump. However, the authors report that air is subsequently penetrating the cover in some areas, possibly due to root penetration, and advise that it is not yet clear whether the oxidation rate will remain at a low level over the course of time.

Bell (1987) advocates the use of a cellular form of construction for acid waste rock piles in situations where there is a sufficient volume of impermeable material within a reasonable haulage distance but emphasizes that this approach has yet to be evaluated under pilot or operating conditions. Patterson (1987) reports the use of till to provide a horizontal seal and sideslope cover to the waste rock dump at the Equity Silver Mine in British Columbia. He states that this treatment represents a small incremental cost over normal operating expenditures and has resulted in a slight downward trend in leachate acidity and metal levels.

Application of sodium lauryl sulphate to the Equity Silver dump was tested after laboratory simulations produced promising results. However, the rock surface could not be effectively saturated and the surfactant biodegraded rapidly under the acidic conditions present.

Taylor (1984) describes the acid waste management systems at the Gibraltar Mine in British Columbia, and states that the possibility of sealing the large waste dumps was considered and rejected as logistically unfeasible. The decision was therefore made to treat contaminated leachate from the dumps rather than apply preventative measures.

This brief review clearly defines the lack of proven technology for the effective long-term management of acid waste rock dumps in Canada or elsewhere. There is, however, a general recognition that preventative methods must reduce the availability of oxygen within the dump to levels of less than 0.5 mg/L; that the ingress of water must be reduced to an absolute minimum to restrict the flushing of reaction products, that the voids ratio should be minimized by compaction of the waste so as to reduce the volumes of entrapped and induced air, and that siting of the dump with respect to surface and groundwater hydrology is of paramount importance.

Review of Alternative AWR Mangement Strategies

The potential options available for AWR management and their economic impact on the profitability of an operation are highly mine-specific. At the present time, collection and treatment of contaminated leachates in perpetuity is the only generally available long-term management option. It is in this perspective that the following alternative management strategies are reviewed:

In Situ Neutralization

In situ neutralization can involve either the addition of alkaline materials such as limestone to the waste rock or alternatively, the blending of acid-consuming material developed in the course of the mining operation. In either case, the objective is to mix sufficient acid consuming material into the waste pile to uniformly offset acid generation in the waste. In the event that acid-consuming materials are economically available, this approach offers the ideal preventative concept in that long-term stability of the wastes can be assured.

In coal stripping operations, the blending approach can be attractive because the required aoid-consuming material is often available onsite and must be stripped and relocated as an integral function of the mining operation. However, this opportunity is seldom available at base metal hard rock mines despite the fact that the characteristics of waste rock can vary from zone to zone within a given mining operation. The cost of mixing offsite neutralizing materials into acid waste rock has been shown to be prohibitive (Nolan, Davis & Associates Ltd., 1987).

Underwater Disposal

This concept can include disposal into natural water bodies, flooded mine workings, or specifically designed retention systems. There is a steadily accumulating volume of field evidence that disposal of reactive mine wastes underwater curtails oxidation to virtually zero levels due to the very low diffusivity of oxygen through water (approx. 2×10^{-6} cm/sec). Shortcomings to this approach include the fact that relatively few metal mines are located within economic haulage distances of suitable natural bodies of water; the concern over the physical impact of waste rock disposal on benthic conditions of a lake or coastal marine environment; and the fact that the long-term effects of lake turnover, natural diffusion of oxygen through water, and the influence of benthic organisms are not as yet well understood.

The opportunity for acid waste rock disposal in flooded open pits is very mine specific and will seldom offer a total solution to the problem due to the added volume of waste caused by swell (often about 30 percent); the fact that open pits will seldom flood back to the surface level, and the economic implications of moving waste back into the pit. However, in many instances, backfilling will provide an attractive means to reduce the volume of wastes requiring other management measures.

It is generally recognized that a fluctuating water level within reactive waste material is a worst possible situation in that conditions in the wetted zone are ideal for the generation of acid and flushing of the reaction products. Thus, where pits are to be filled above and below the water table, it is essential that the range of water fluctuation be defined and a layer of nonreactive material placed in this zone so as to avoid the fluctuation of water through acid-generating wastes.

The practicality of providing engineered underwater disposal systems for acid waste rock should be evaluated with respect to the cost of providing very large subaqueous storage volumes an concerns over the long-term safety and stability o manmade retaining systems.

Use as Underground Mining Backfill

In circumstances where acid waste rock exists in close proximity to an underground mining operation, the possiblity of using it as mine backfill can be considered. Normally preferred criteria for mine backfill are as follows:

- nonreactive, nonfriable
- minus 15 cm size range
- minimum transportation costs

The use of reactive acid rock as backfill is compromise from the mining standpoint as it can lead not only to the generation of highly contaminated acid drainage within the mine, but also to the possiblity of an uncontrollable exothermic reaction within the backfill. This has occurred at several metal mines in Canada including the Brunswick No. 12 Mine in New Brunswick and the Sullivan Mine in British Columbia.

Waste Pile Sealing Techniques

To be totally effective, any sealing system for AWR storage systems must eliminate the throughput of moisture and reduce oxygen levels within the system to less than 0.5 mg/L. In principle, this would require the following:

(1) Top cover to prevent the infiltration of rainfall and air diffusion.

(2) Sideslope cover to prevent rainfall infiltration, air diffusion, and induction.

(3) Stabilization of top and side covers to prevent wind and water erosion.

(4) Prevention of penetration of the cover by roots, animals, traffic, etc.

To date there are no recorded cases of totally effective sealing sytems for acid waste rock dumps. The best documented case is the previously mentioned Rum Jungle pyritic waste piles in Northern Australia, but even there the long-term effectiveness of the cover is open to question.

The advantages and disadvantages of various cover materials are described in table 2. Composite covers designed to prevent the desecation of clay or till would be expensive, but may warrant further investigation. An example might consist of the following:

Table 2.--Alternative cover materials for waste rock dumps (depending on local availability).

Cover Material	Permeability to Water (m/sec)	Advantages/Disadvantages
Compacted clay	10^{-9} - 10^{-11}	Large quantities problematic in many areas. Subject to erosion, cracking, and root penetration. Good sealing if protected and maintained.
Compacted till	10^{-7} - 10^{-9}	As above, but generally more permeable.
Compacted topsoil	10^{-5} - 10^{-8}	As above, but less robust, more permeable. Questionable longevity.
Peatland bog	10^{-5} - 10^{-6}	Need to maintain in saturated condition. Normally impractical for elevated waste dumps and side-slopes.
Concrete	10^{-10} - 10^{-12}	Subject to cracking, frost, and mechanical damage.
Asphalt	10^{-20}	As above.
HDPE synthetic cover	Impermable	Requires proper bedding and protective cover. Highly impermeable. Lifespan unlikely to exceed 100 years. Subject to root and mechanical penetration.

surface vegetation--stabilize surface/ aesthetics 20 cm

topsoil--prevents desiccation of clay 20-30 cm

coarse material--root barrier 50-200 cm

clay/till--provides saturated seal 20-30 cm

coarse material--capillary break

The risk and implications of cover failure can be reduced by providing a series of seals throughout the dump through the use of cellular construction as described by Bell (1987). This approach, shown diagramatically in figure 2, not only limits the implications of local failures in the surface seal, but also allows control to be exercised over the rate of oxidation by the application of bactericides or other means as the dump is constructed. This is an extremely important consideration bearing in mind that the life of a mine can extend over several decades and that the oxidation process will start in the waste as soon as it is exposed.

Bactericides and Inhibitors

In field trials on coal spoils sodium lauryl sulphate has been used successfully with the beneficial effects lasting up to 6 years if applied in the form of rubber matrix pellets (Sobek 1987). However, trials of its effectiveness on hard rock wastes currently indicate difficulties in saturating the surface of the waste rock throughout the potential reaction zone. Despite these difficulties, it appears that SLS or other reagents may prove of value for controlling the biological rate of oxidation in acid waste rock dumps as long as it is used in a preventative manner before extreme acid conditions become established and prior to applying more permanent control measures. As previously mentioned, its use in association with cellular dump construction may, for example, prove advantageous.

Passive Treatment

With the possible exception of underwater disposal, none of the previously discussed methods of managing waste rock have proven to be totally effective in preventing the formation of contaminated leachate. The need to provide downstream treatment is therefore likely to persist. A number of wetlands have been established in the Eastern U.S. coal regions to provide passive treatment of acid drainage (Pesavento 1987, Kalin and Everdingen 1987). Experimental work on passive treatment methods is being undertaken at a number of mine sites in Canada with a view to evaluating the effectiveness of these systems under Canadian conditions and with respect to their ability to handle peak flows and high concentrations of metals under long-term stress conditions.

Conventional Treatment Systems

At the present time, collection and treatment of acid drainage is the primary means of controlling contaminated leachates from acid waste rock dumps. The cost of maintaining such systems in perpetuity as well as the implications of treatment sludge disposal are well recognized. The technology for AMD treatment is well established and described extensively in the literature (e.g., Monenco 1986, Vachon et al. 1987)

Other potential methods for AWR management that have been identified include the creation of anaerobic conditions by incorporating organic material into the dump, integrated disposal of AWR with mine tailings to reduce air diffusion into the waste rock, segregation of acid-producing material to reduce the volume requiring special measures, and milling of reactive rock in situations where the recovery of metal values and reduced long-term management costs might offset the cost of processing. All of those methods require further evaluation before their effectiveness or practicality can be fully assessed.

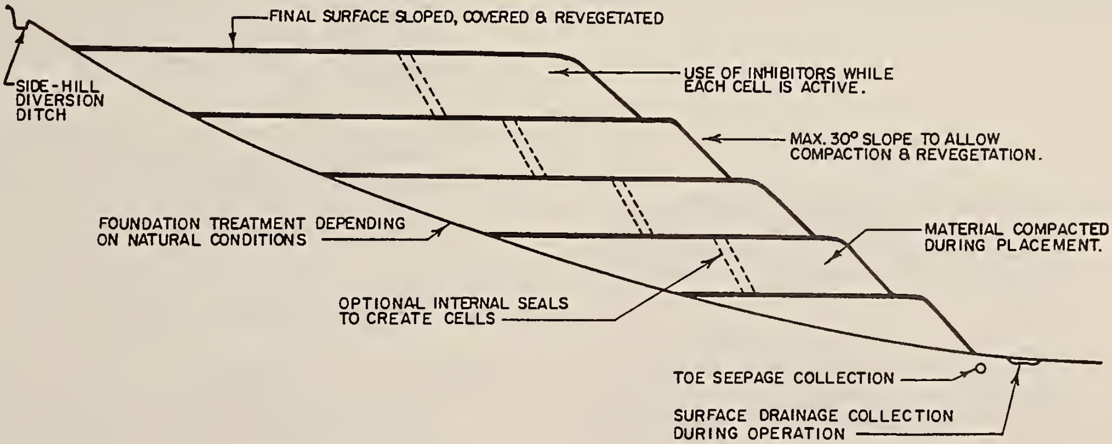
FINAL SURFACE SLOPED, COVERED & REVEGETATED
SIDE-HILL DIVERSION DITCH
USE OF INHIBITORS WHILE EACH CELL IS ACTIVE.
MAX. 30° SLOPE TO ALLOW COMPACTION & REVEGETATION.
FOUNDATION TREATMENT DEPENDING ON NATURAL CONDITIONS
MATERIAL COMPACTED DURING PLACEMENT.
OPTIONAL INTERNAL SEALS TO CREATE CELLS
TOE SEEPAGE COLLECTION
SURFACE DRAINAGE COLLECTION DURING OPERATION

FIGURE 2 - CONCEPTUAL CROSS-SECTION OF CELLULAR CONSTRUCTED DUMP

AFTER BELL, 1987

RESEARCH RECOMMENDATIONS

The following categories of applied research were identified in the Acid Waste Rock Study:

(1) Investigation into acid generation mechanisms in AWR including effect of various dump parameters; relative roles of oxygen diffusion, convection and trapped air, and bacterial mechanisms in force as internal dump temperatures increase.

(2) Development and calibration of acid generation predictive techniques for AWR.

(3) Investigations into AWR management methods including:

- long-term effectiveness and potential impact of underwater disposal
- effectiveness of cellular construction techniques
- definition of the permeability, air diffusivity, and longevity of various waste dump cover materials and then effectiveness in controlling acid generation
- use of bactericides and inhibitors on AWR dumps
- development of criteria for the use of AWR as mine backfill
- creation of anoxic conditions in AWR dumps through use of organic methods

(4) Evaluation of passive treatment alternatives, including wetlands, for AWR dump leachates.

(5) Case studies at operating mines to define alternative AWR management strategies and their implications to production economics and lifetime costs.

These recommendations have now been integrated into the national Reactive Acid Tailings (RATS) Program.

CONCLUSIONS

1. Preventative management methods for controlling the generation of acid in sulphidic waste rock at base metal mines in Canada and elsewhere are in their infancy.
2. There is no proven method of AWR management for which backup leachate collection and treatment is not required in most circumstances, with the possible exception of underwater disposal.
3. The effectiveness of passive treatment systems to handle residual leachate flows is unproven in Canadian conditions.
4. Knowledge does exist to site and design AWR dumps so as to minimize the generation of contaminated leachates. Well-constructed covers and seals can be effective in this regard although some ongoing maintenance will likely be required in most circumstances. Evaluation of alternative systems under field conditions is required.
5. Use of sealed waste dumps constructed on a cellular basis appears to have promise as does underwater disposal in natural waters or manmade systems. These approaches should be further evaluated.
6. The ability to predict the extent and form of acid generation in AWR is important to the selection and design of management systems as well as to the assessment of long-term mining costs.

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DERELICT LAND RECLAMATION IN THE UNITED KINGDOM[1]

Derek Hartley and Paul Wright[2]

Abstract.--In 1966 there was a total of 52,000 ha of derelict land in the United Kingdom, of which approximately two-thirds was either capable of or required treatment. This fact, coupled with the Aberfan disaster in 1967 led to public demand that this land be reclaimed to recreate new land for the regeneration of the country's industry and to improve the welfare of the areas where dereliction was most prevalent. Most local authorities in the coalfield areas, which was where the most dereliction was concentrated, set up special teams to deal with the problem. Their work was assisted by the formation of the Standing Panel of Local Authority Officers on Land Reclamation, which meets to disseminate information, to organise research, and to advise the government on reclamation matters. Seven completed reclamation schemes are described, three from County Durham, and two each from Derbyshire and Mid Glamorgan, showing the aims of the design and the methods used to achieve it. By reshaping the spoil heaps, recontouring, constructing new watercourses and drainage systems, providing flood control measures, covering with topsoil, and planting or seeding, these areas have been restored to such land uses as industry, housing, agriculture, woodland, and recreation.

INTRODUCTION

In the United Kingdom 1967 is generally seen as a watershed in derelict land reclamation. On October 21st of that year a coal tip at Aberfan in South Wales slipped and caused the deaths of 116 children and 21 adults. This tragedy generated an anger directed at the many spoil heaps littering not only the South Wales Valleys, but all the coalfields throughout the country. This soon resulted in action by all local authorities in the coalfields to set up reclamation teams to deal with and remove the problems.

[1] Paper presented at the 1988 Mine Drainage and Surface Mine Reclamation Conference sponsored by the American Society for Surface Mining and Reclamation and the U.S. Department of the Interior (Bureau of Mines and Office of Surface Mining Reclamation and Enforcement), April 17-22, 1988, Pittsburgh, PA.

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EVALUATION AND TREATMENT OF DERELICT LAND

Prior to this date reclamation work had been done on an ad-hoc basis. Records exist of tree planting carried out in 1908 on spoil tips in the Midlands by the Midland Re-afforesting Association. Other work was done after World War I to reclaim small spoil heaps with hand labour as unemployment relief. After World War II the Distribution of Industry Act 1947 allowed grants to be paid towards reclamation costs where the work would enhance the long-term employment prospects of the area. Some local authorities made use of these grants to plant some derelict tips, but it was not until the 1960 Local Employment Act giving grants of 50%, later raised to 85% in certain areas, that local authorities were able to make inroads into the problem of dereliction. The grants covered not only the cost of the works, but also the cost of land acquisition, where necessary, and design and supervision costs, less any increase in the value of the land after reclamation. These grants were later increased to 100% for local authority schemes and 80% for private ones.

The Aberfan disaster raised the consciousness of the nation towards dereliction. What had been seen as signs of prosperity, or former prosperity, were now seen as a blight on the neighbourhood and could no longer be tolerated. Apart from this aspect, the country could not afford to allow so much land to remain derelict. Dereliction, defined as "land so damaged by industrial or other development that is incapable of further beneficial use without treatment" accounted, in 1966, for 0.29% of the total area of England. However in coalfield areas this proportion was a lot higher; for instance, in the Urban District of Ince-in-Makerfield, 37% of the area was derelict. At that time there was approximately 38,000 ha of derelict land in England, 8,000 ha in Wales, and 6,000 ha in Scotland of which approximately two-thirds was capable of, or required treatment. For a country the size of Great Britain these figures were too high. (Barr 1969).

One other principal reason why land needed to be reclaimed was the desire to improve the self-respect of communities afflicted by dereliction, and the need to improve the appearance of rundown areas trying to attract new investment. Communities which had tolerated gross dereliction for so long had also tolerated shabby housing standards, poor civic amenities, and a general untidiness and scruffiness of the area. The clearance of dereliction can give an impetus to local improvement campaigns and help to restore some civic dignity to a community.

The nature and extent of derelict land in Britain is extremely varied. The various coalfields in Britain all have their own character, either in terms of the coal and spoil produced or in the topography of the land in which they exist. For example, some of the Midland coalfields produce spoil which has a high fine fraction so that washeries tailing lagoons cover large areas and are difficult to treat. In South Wales the spoil is coarser, but problems still exist because the collieries are situated in the bottom of very narrow, steep-sided valleys with spoil heaps perched halfway up the valley side.

Given the industrial history of Great Britain, it is not surprising that there are a multitude of different types of dereliction sometimes crammed alongside one other. Abandoned collieries with steel works and gas plants are common partners in many old industrial areas, complemented by old chemical works in Cheshire and Lancashire, limestone quarries with mounds of lime waste in Derbyshire, china clay workings in Cornwall, and lead mining in various parts of the country to name but a few. Each county has its own range of dereliction and of course its own range of particular needs giving rise to a variety of afteruses.

By the early 1970s most local authorities, either County or District Councils, had established multidisciplinary teams to tackle the derelict land problem. Early reclamation schemes were often carried out with the sole purpose of removing the visible scars of dereliction and returning the sites to agriculture or public open space. Over the years however, both the public and reclamation authorities have become aware of the potential that reclamation can open up. If large amounts of spoil are to be moved and money spent, it is worthwhile preparing a scheme that can best suit the needs of the community and make the best use of the land available. Modern reclamation schemes can therefore be complex in their scope and integrated with proposals for transportation, housing, industry, waste disposal, energy production, and leisure and reclamation facilities. It is often worthwhile to include other nonderelict land in the scheme so that whole areas are regenerated using the reclamation scheme as the catalyst.

PREPARATION OF SCHEMES

The more complex schemes mean that much more time has to be spent on preliminary studies, ground investigations and consultations. Preliminary studies of old editions of Ordnance Survey maps, mining and geological plans and other old records are followed by investigations onsite. From the information obtained, preliminary comments can be made on the range of afteruses proposed by local community leaders, other local authorities and user groups.

From their knowledge of the area, the reclamation team members themselves can influence the choice of afteruses for the scheme or suggest better ways of using the land available. Public meetings are often held to give the public the chance to see plans of proposals before they are put into their final form. Detailed planning applications can then be made, and drawings and contract documents finalised. This process can take some time and must be complemented by the process of land assembly.

Local authorities in Great Britain, both at District and County level, have the powers to compulsorily acquire derelict land for the purposes of reclamation plus such other land as may be required for the scheme. This is only used when negotiations for the purchase have broken down and only then as a last resort after a public enquiry and with the approval of the Secretary of State for the Environment. Private owners are encouraged to carry out their own reclamation, and government grants are available assist them, but it is often the case that owners will not or do not want to involve themselves in this work. Occasionally the local authority may wish to have an area covering several ownerships reclaimed together. This makes a lot of sense when an overall objective can be achieved by, for example, transferring spoil from one site to another, or unifying the landscape when two tips are adjacent plots separately owned.

The basic design of the reclamation scheme produced by the reclamation engineer is made after constant interchange of ideas with other team members. After problems of stability, the next problem is usually that of drainage, especially on areas of high rainfall or on steep slopes. The reclaimed site is most vulnerable when the site has just been completed, with no grass cover and therefore subject to maximum run-off, and so drainage channels have to be designed to allow for these worst conditions. As most dereliction occurs in areas that were first developed over 100 years ago, the land drainage of the area often uses drains and culverts constructed at that time and may have been affected by mining subsidence. This presents an opportunity to replace or update the old drainage system.

Many schemes are still designed for an agricultural afteruse, but modern, heavy, earth-moving plant is not generally conducive to good landscaping as it compacts the spoil too much. Even when topsoil and subsoil are available to spread over the spoil, great care has to be taken not to compact this precious commodity; at the same time measures have to be taken to relieve the compaction in the spoil. The choice of species, grass or trees, that will grow on reclaimed sites has been the subject of a great deal of research, not only in Britain. New species have been produced which will grow on unhospitable spoil, such as lead waste, as well as specied being identified as being the best to suit the various types of spoil and the vagaries of the British weather.

Another aspect of reclamation that must be taken into account is coal recovery. All spoil heaps have to be checked for recoverable coal content before reclamation starts. Apart from the fact that the value of the coal recovered can help offset the cost of reclamation, it is worthwhile to reduce the amount of combustibles in the spoil to prevent future spontaneous combustion, especially if the site is to be developed. Not all tips have a coal content that is economic to recover, but the proportion that have has led to a substantial coal recovery industry being developed with highly sophisticated plant to recover the coal down to 0.25mm and to dewater the fine material to allow it to be disposed of with the rest of the discarded spoil.

Coal recovery schemes are not universally popular with local residents and council representatives. Coal recovery schemes take longer to complete and also bring more noise and dust to sites which may have been idle for a number of years. Generally though, communities are happy to accept coal recovery as part of a reclamation scheme where they can see some benefit to the area

STANDING LOCAL AUTHORITIES PANEL ON LAND RECLAMATION

Different problems encountered in different areas lead to a variety of solutions. In order that these experiences could be brought together for the benefit of all reclamation authorities and the government, who oversee the reclamation programme, a Standing Panel of Local Authority Officers was formed in 1973. The Panel, whose membership is open to all Reclamation Authorities, meets twice a year to discuss all aspects of reclamation, from details of construction contracts to the administration of Derelict Land Grants, and is aided by several specialist subcommittees that meet more frequently.

The Engineering Sub-Group covers items such as treatment of toxic waste and washery tailings, new materials available for land drainage work, preparation of contract documents where coal recovery is included in the works, compaction of spoil and the relief of compaction when necessary, difficult demolitions, and all engineering aspects of reclamation.

The Vegetation and After-Management Sub-Group is concerned with the design of schemes alongside the engineer and the specialist skills needed once the engineer work has been completed. Through their endeavors over the years civil engineers now take more notice of the vegetation and affirmance needs in the preliminary design stage than they used to. The Sub-Group has concerned itself in grass and tree growth, use of fertilisers, methods of planting, and different aspects of land management.

Other Sub-Groups have been responsible for conducting surveys on design costs, preparing advice for the government on various aspects of derelict land reclamation, and collecting and disseminating information pertinent to land reclamation. The government has sponsored several research projects that have been suggested by the Panel and its Sub-Groups, who have been represented on the research project management panel. These projects have included the treatment of colliery tailings, location and treatment of shafts and adits, management of colliery tailing, location and treatment of shafts and adits, management of reclaimed agricultural land, and the growth of trees on colliery shale.

DESCRIPTIONS OF SCHEMES

The following descriptions of seven reclamation schemes are typical of many carried out during the last few years in coalfield areas and show the different emphasis that the three counties, Durham, Derbyshire and Mid Glamorgan, put on the afteruse for the sites.

Mainsforth Colliery Reclamation Scheme, County Durham

This site, situated approximately 8 miles southeast of Durham City, was one of the largest pit heaps in the county. It is bounded to the east by the main railway line and on the west by the River Stell. Directly to the north is an industrial area and on the south is an area of agricultural land. Further east is more agricultural and woodland and the village of Mainsforth.

The area of land to be reclaimed was 44 ha, completely covered by colliery waste heaps and slurry lagoons. To assist in spreading the spoil to more appropriate contours, a further 24 ha of agricultural land and 1 ha of woodland were "borrowed" to accommodate the surplus spoil. The afteruses for the site included 26 ha of woodland, 18 ha of new agricultural land and the 24 ha of land returned to agriculture. The remaining land was designated as an extension to the Mainsforth recreation ground and an extension of the industrial estate if that was ever needed.

During the works a total volume of 2.1 million m3 of spoil were moved to lower the tip by a maximum of 28 m, in addition 70,000 m3 of slurry was removed from the slurry lagoons. Due to the acid nature of the spoil, a total of 45,000 m3 of topsoil were imported to provide an adequate cover to establish good grass growth.

Alma Pit Reclamation Scheme, West Pelton, County Durham

The former Alma Colliery lies south of the settlement of Grange Villa and straddles country road. To allow the tipping of spoil, the National Coal Board had diverted the Twizell Burn through a large culvert which had subsequently become a source of concern. Substational depths of material had subsequently become a source of concern. Substantial depths of material had been tipped over the culvert, thus destroying the effect of the pleasantly wooded valley and creating an area of dereliction visible from much of the surrounding area. Burnt shale workings, abandoned mineral railways, and a substantial refuse tip completed the general effect of squalor.

Insufficient council-owned land was available to dispose of all the spoil material, but 6 ha of adjacent farmland was acquired under a license agreement to dispose of some of the fill. This allowed the formation of a shallower valley at a higher level than the original, removing the need for the culvert and the restoration of the farmland to an improved standard.

It was necessary to rejoin the original watercourse by means of a cascade and stilling basins with a total drop of 20 m. Alternative methods of construction were considered, but gabions was the method adopted. The road was crossed by a 1.9-m-diameter culvert, the old railway bridge and pithead buildings were demolished, and the shafts were capped before the 460,000 m3 main earthworks were carried out. Construction of a new footbridge has allowed the reopening of a public footpath across the site, and the extended system of paths and tracks has given the public access to a pleasantly wooded area.

As the result of an unprecedented combination of snowmelt and heavy rain shortly after the scheme had been completed, the 1.9-m-diameter culvert under the road was overloaded and failed due to piping in a local sand pocket, and the gabion cascade collapsed. A new watercourse was then constructed, consisting of a concrete channel and cascade, and a piled culvert with a concrete stilling basin upstream and downstream.

The site has produced 22 ha of woodlands, 6 ha of new agricultural land and 3 ha of public open space adjacent to the housing. This is in addition to the 6 ha of licensed land restored to agriculture. Steep slopes on much of the land precluded any uses other than woodland.

Handenhold Colliery Reclamation Scheme, County Durham

The site of the old Handenhold Colliery is situated near West Pelton in the District of Chester-le-Street and consisted of 36 ha of derelict land. Before handing over the derelict land to the County Council, the National Coal Board indicated that they wished to carry out some opencast mining on the site and in addition work a further 23 ha of adjacent agricultural land. Since opencast mining is a particularly sensitive subject in coal mining areas, where local communities see it as a threat to jobs in the deep mining industry, and in the light of the resolve of the Chester-le-Street District Council and the County Council to enhance the area with an 18-hole golf course, the National Coal Board agreed to restore the opencast land to provide levels and contours suitable for a golf course. The Board also agreed to include in the work, for a negotiated price, pockets of derelict land outside the opencast area, which had been in the County Council's original reclamation proposals.

The new landform was designed by the County Land Reclamation Team and, under their supervision, the site was completed to the new contours in April 1983. Construction of the golf course then proceeded with grants from a number of bodies, including the National Coal Board, Department of the Environment, Sports Council, and the Countryside Commission. The area now contains 1 ha of agricultural land, 8 ha of open space, 2 ha woodland and an impressive 53 ha 18-hole golf course.

Grin Low Reclamation Scheme, Buxton, Derbyshire

The 36-m high lime waste heaps of Grin Quarry used to be a dominant eyesore on the western approaches to Buxton, close to the Peak District National Park in Derbyshire. The grey-white tips were too steep to take any vegetation and only extensive reclamation work has allowed the levels to be lowered and slopes reduced in order that grass and trees can grow on them.

The total area of the 63-ha site included the old quarry and its surrounding spoil heaps of reject stone and lime waste which in places was as solid as concrete. The reclamation work included the regrading of the limewaste heaps to partly fill in the quarry floor. A total of 500,000 m3 of material was moved before imported topsoil from neighbouring quarry soil stripping operations was spread over the site, followed by seeding and planting.

As the original drainage of the site via natural swallow holes in the limestone had been covered over in the reshaping process, a complete new drainage system had to be built to take the runoff down to the River Wye. This consisted of a series of channels lined with concrete slab inverts and natural stone sides, leading to a catchpit with a 1-m-diameter culvert under the road and down to the river.

The drainage of the remaining part of the quarry, which is still in a depression, is still via an existing sinkhole. This part of the site is occupied by a 150-unit touring caravan site, occupying 4 ha, developed by the Caravan Club which has become a popular site from which the town of Buxton and the adjacent Peak District National Park can be explored.

Of the remainder of the site, 40 ha have been restored to sheep grazing land and 18 ha to woodland.

Glapwell Colliery Reclamation Scheme, Derbyshire

This scheme covers an area of 126 ha, the major part of which was derelict, comprising the old colliery yard, shafts and spoil heaps, coal treatment plant, and disused railway sidings. The site is close to the residential areas of Glapwell and Doe Lea and is particularly prominent from the M1 motorway and its Heath interchange.

The reclamation of the site included the reshaping of the spoil heaps, involving moving some 2.5 million m3 of spoil and the demolition of old structures and diversion of overhead power lines. The final afteruse of the majority of the site is agriculture and woodland, however as an intermediate afteruse three voids for refuse disposal have been formed and their combined capacities of over 2 million m3 will provide tipping facilities for the northeast are of Derbyshire until 2002.

Concurrently with the reclamation scheme, opencast coaling has taken place, in two places, as an integral part of the scheme and in addition, coal recovery by tip washing has been carried out.

Clydach Vale Reclamation Scheme, Mid Glamorgan.

Clydach Vale is a narrow side valley off the Rhondda Valley approximately 1 1/2 miles long. It contained the remains of two main collieries plus several small mines and drifts and before reclamation started, the valley floor was carpeted from one end to the other with spoil tips, tailings lagoons, and derelict structures. The Nant Clydach was culverted in two places and both culverts were in a bad state of repair. The village of Clydach clings to the northern side of the valley.

Initial consultations showed that the area required land for housing and industry but, in addition, the whole area was rundown and needed an uplift. Parts of the Rhondda nearer to Cardiff were becoming more prosperous, whilst areas, such as Clydach, were being forgotten and neglected by new industry, basically because there was no land for development.

The reclamation of the valley was originally seen as being two schemes, one for each end of the valley, but the investigations had not proceeded very far before it was decided to amalgamate the two schemes into one, covering a total area of 73 ha. The scheme covers the whole length of the valley so it can be appreciated that the maximum width of the site is only some 300 m.

In order to find more space for the spoil, the Nant Clydach was raised and diverted to the north side of the valley and to assist in flood control, two small lakes with surface areas of 0.5 and 1 ha were formed. The new stream course has been made as natural looking as possible with local block stone forming the side walls and the invert on the steeper and cascade sections.

A 6-ha area for industry plus 4 ha for housing have been formed at the lower end of the valley overlooking the larger of the two lakes, whilst the remainder is being laid out for public open space and recreation. A system of footpaths and tracks will encourage not only local residents but, hopefully, tourists to explore the areas beyond the head of the valley and beyond.

Gelliwion Valley Reclamation Scheme, Mid Glamorgan

The Maritime Colliery and spoil heaps are situated less than half a mile from the centre of Pontypridd which is one of the major towns in the County of Mid Glamorgan, situated at the confluence of the Rivers Taff and Rhondda. When the colliery closed, a small reclamation scheme was carried out by the District Council to form a small industrial estate on part of the colliery surface. No attempt was made at that stage to deal with the rest of the site, including the very large, dominant spoil heap, or the surrounding area, which even then was looking semi-derelict and rundown.

In 1974 the County Reclamation Team was asked to prepare a scheme for the remainder of the site. The remaining dereliction included the remains of the colliery buildings and coal preparation plant, two large shafts, large retaining walls, a 150-m-long culvert in a poor condition,an abandoned mineral railway line, and the spoil heap that had been badly worked over by a coal recovery contractor, leaving quantities of tailings and tailings lagoons all over the place.

The bulk of the site was acquired from the National Coal Board but additional areas were needed to assist in reshaping the spoil. Identifying the areas needed for the scheme, obtaining the powers to compulsorily acquire the additional plots and convincing the Welsh Development Agency that this was a scheme worth spending over a million pounds on took most of ten years before the scheme was able to start.

The additional land was required to provide sufficient space for spoil so that a significant difference could be made to the shape of the tip. With the additional land, it was possible to move and lift the Nant Gelliwion into a new lined channel to provide the required amount of space. This also made it possible to remove the old culvert.

Opportunity was taken to improve the site infrastructure by realigning the old, narrow, twisting access that had been constructed when the colliery first opened, nearly a hundred years ago. With the mineral railway and colliery yard redundant, the old bridges which had provided a straight jacket for the old road, could be demolished and a new alignment, although still of necessity steep, could be achieved.

Even after the scheme it has only been possible to extend the industrial estate by 4 ha, but in Pontypridd, that is a considerable amount of land. The remainder of the site is mostly reshaped spoil heap and its slopes of up to 1:3 are only suitable for woodland or open space.

CONCLUSIONS

During the period 1964-82 30,000 ha of derelict land has been reclaimed in England, but during that time the amount of derelict land increased by 44,000 ha (Hartley 1984) The big shake out in industry over the last several years has meant that large numbers of collieries and steelworks, cotton and woollen mills, railways and other old industrial workings have closed. Most of them date back to the time before planning controls on reinstatement of sites existed, so the owners of the sites, factories, mills, or works can not be obliged to carry out any reclamation at their own expense.

Whilst this state of affairs continues, there remains a substantial amount of work for reclamation authorities. It is an opportunity to create new land for the next generation, and a challenge to improve the lives of present communities by improving the appearance of derelict land.

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MUSHROOM COMPOST AND PAPERMILL SLUDGE INFLUENCE DEVELOPMENT OF VEGETATION AND ENDOMYCORRHIZAE ON ACID COAL-MINE SPOILS

Willis G. Vogel and Frederick M. Rothwell[1]

Abstract.--Several rates of spent mushroom compost and papermill sludge were evaluated as amendments in revegetating abandoned acid mine spoils (pH 3.3 to 4.1). In a greenhouse study, the combined yields of five harvests of a perennial ryegrass (Lolium perenne)-red clover (Trifolium pratense) mix were 2 to 4 times higher in spoils amended with a 1:1 sludge-compost mix and with compost alone than in spoils amended with sludge alone or with lime plus mineral fertilizer. Yields increased with each higher rate of compost, sludge, or mix, i.e., 25, 50, and 75 g of air-dry material per 1000 g of air-dry spoil. Herbage yields in the lime-fertilizer pots declined rapidly after the second harvest, but continued fairly steady through the five harvests in the compost and sludge treatments. Results followed a similar pattern in field plots except that herbage yields were more nearly alike in sludge and compost treatments. Compared to the lime-fertilizer treatment, endomycorrhizal formation was enhanced by additions of papermill sludge and a 1:1 mixture of sludge and compost, but inhibited at all levels of treatment with mushroom compost alone. High levels of phosphorus in the compost were most likely responsible for this inhibition of endomycorrhizae. These experiments show that mushroom compost and papermill sludge are useful materials to aid revegetation of acid spoils, though the long-term effect of mycorrhizal inhibition in compost-treated spoils could not be predicted in this study. The estimated cost of applying these organic materials was about 2.5 times that of applying appropriate rates of lime, mineral fertilizer, and mulch, but yields of vegetation also were 2 to 3 times greater from the compost and sludge amendments.

INTRODUCTION

Acid spoils abandoned after surface mining for coal are commonplace in some areas of the Eastern United States. Most of these sites were mined before State and Federal laws and regulations were enacted to control mining and reclamation practices. Some of these abandoned mines have been revegetated by natural processes, though in some localities barren or sparsely vegetated spoils still exist and need treatment to support vegetation.

Acid-mine spoils usually lack nitrogen and organic matter, often have low levels of plant available phosphorus, and have little or no structural stability. One procedure in reclaiming these spoils is to apply agricultural lime and mineral fertilizers to neutralize acidity and enhance plant growth. Sometimes, topsoil or better quality spoil is available to cover the acid spoil. Abandoned mine sites in some localities have been successfully revegetated by using large inputs of municipal wastes such as sewage sludge (Mason 1985, Sopper and Kerr 1979). In southeastern Ohio, a sludge-like residue recovered by primary and secondary treatments of effluent from the Mead Paper Corporation plant (Kraft process) at Chillicothe has been used in successfully reclaiming acid-mine spoils (Hoitink and Watson 1980, Hoitink et al. 1982). Spent mushroom compost is another industrial residue that is available in some localities for mined-land reclamation use.

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Interest in reclaiming surface-mined lands often focuses on success in amending acidic spoils and promoting vegetational growth. Though not so conspicuous, the biological components of soil also play a vital role in the development and maintenance of vegetation (Vogel 1981). Studies by Wilson (1965) on rhizosphere microorganisms, and later by Schramm (1966) on microbial symbionts, were among the first to define and demonstrate the significance of microorganisms in minesoil revegetation. More recently, microbial interactions with plants have been shown to be some of the most influential factors in aiding plant establishment, particularly those interactions between mycorrhizal fungi and their host plants (Allen 1985, Cundell 1977, Fresquez and Lindemann 1982). The significance of the formation of endomycorrhizae by VAM fungi is most apparent where levels of mineral nutrients in the soil limit plant growth. In such cases, an extensive mycelium or thread-like growth produced by the fungi permeates the rhizosphere and increases manyfold the capacity of the host plant to absorb nutrients. Where levels of mineral nutrients, particularly P, are high in soils, little or no plant-fungal association is observed.

Papermill sludge has been frequently used for amending acid-mine spoils; however, less is known about spent mushroom compost as an amendment for these sites. Therefore, in the spring of 1983, studies were set up to compare this compost with papermill sludge and with lime plus fertilizer as treatments for acid-mine spoils. Herbage yields were used as the primary means for evaluating the comparative effectiveness of the amendments; the influence of these amendments on formation of endomycorrhizae by the VAM fungi also was evaluated.

MATERIALS AND METHODS

Greenhouse and field studies were established using acidic spoils from abandoned surface mines in southeastern Ohio. Spoil for the greenhouse study was collected from two sites on the Wayne National Forest: Hanging Rock in the Ironton Ranger District and the Weltzheimer Tract near Nelsonville in the Athens Ranger District. Plots for the field study were established at the Hanging Rock site only.

Greenhouse Pot Study

Pots were filled with 2,000 g of spoil screened through a 13-mm mesh sieve. For each spoil, 44 pots were prepared to accommodate 4 replications of 11 treatments as follows:

None (Control)
Lime plus fertilizer
Papermill sludge at three rates
Mushroom compost at three rates
A 1:1 mix of papermill sludge and mushroom compost at three rates

For the lime plus fertilizer treatment, 7 g of laboratory grade $CaCO_3$ (precipitated chalk) was added per 1,000 g of Hanging Rock spoil and 5.5 g per 1000 g of Weltzheimer spoil. The buffer pH test of Shoemaker et al. (1961) was used to determine liming rates. Fertilizer added was 50 ppm of N as NH_4NO_3; 100 ppm P_2O_5 as basic calcium phosphate; and 25 ppm K_2O as KCl.

The three rates of papermill sludge and compost were 25, 50, and 75 g of air-dry material per 1,000 g of air-dry spoil. This is similar to a field application of 56, 112, and 168 t/ha (15-cm furrow slice). For the three rates of mix, one-half of these rates of each material was used.

The amendments were mixed thoroughly in the spoils. The pots were then seeded by placing 50 seeds of perennial ryegrass (Lolium perenne) on one-half of the surface area of a pot and 50 seeds of red clover (Trifolium pratense) on the other half. Water was added equal to 20 to 25 percent of the weight of the spoil-amendment mix. Thereafter, pots were watered daily to maintain this moisture level.

The first harvest of vegetation was made 60 days after seeding. Four succeeding harvests were made periodically through the next 10 months. The plants, harvested separately by species, were cut 5-7 mm above the soil surface. Vegetation was ovendried and weighed.

Field Study

For the field study, three replications of seven treatments were applied on 16- by 16-m plots at the Hanging Rock site near Ironton, OH. The treatments were agricultural lime (16 t/ha) plus fertilizer (560 kg/ha 10-10-10); papermill sludge and mushroom compost each at two rates equivalent to 76 and 112 air-dry t/ha; and a mix of sludge and compost at two rates equivalent to 38 and 56 air-dry t/ha of each material. The high rate of sludge and compost treatments was similar to the intermediate rate used in the greenhouse study. The sludge and compost were applied wet; the materials used contained about two-thirds water by weight. Lime, papermill sludge, and compost were disked about 13 cm into the spoil. Fertilizer was broadcast on the tilled surface of the lime plus fertilizer plots, and a mix of grass and legume seed was sown over the entire area. Herbage yields were determined in September by clipping vegetation from five randomly placed 0.223-m^2 quadrats in each plot. The herbage was oven-dried and weighed.

Endomycorrhizae Analysis

Roots from plants in greenhouse pots and field samples were soaked in water to remove the bulk of the soil material, then carefully washed free of adhering soil with a fine spray of water. Terminal portions of the root system including the finest order of root branching were cut into segments approximately 2.5 cm in length and stained to detect presence of VAM fungi (Phillips and Hayman 1970). Percent mycorrhizae was determined on the basis of microscopic observations of 100 stained root segments from each of the treated spoils. Spores were obtained by wet sieving the soil.

RESULTS AND DISCUSSION

Characteristics of Spoil Materials

Pertinent characteristics of the spoils used in the greenhouse study are listed in table 1. Bray P_1 phosphorus and pH of spoil samples collected from the greenhouse pots 10 months and five harvests after seeding are shown in table 2. The overall higher pH, and higher levels of phosphorus, calcium, and magnesium in the Hanging Rock spoil presumably resulted from an application of lime and fertilizer on that area the preceding fall. The pH of the spoils was adequately raised by all treatments except by the low rate of compost in the Weltzheimer spoil. Values of Bray phosphorus were higher in the compost treated spoils than in those treated with papermill sludge or the mix.

Characteristics of Organic Amendments

Some of the properties of the papermill sludge and mushroom compost are listed in table 3. The papermill sludge is especially high in calcium, and the compost high in P and K. The sludge contains a high percentage of kaolinite clay used in the papermaking process. Compost for growing mushrooms is prepared by mixing horse manure and straw with peat moss, brewers grain, gypsum, and lime. The compost used was stockpiled outdoors for about 6 months after removal from the mushroom plant. Nitrogen content was about 1 percent for the sludge and about 2.6 percent for compost. At the application rate of 112 air-dry t/ha the nitrogen content of the sludge was equivalent to 1,120 kg/ha and 2,800 kg/ha for the compost. The availability of the N in these materials relative to the mineral fertilizer was not evaluated. The sludge provided about 201 kg P/ha and 280 kg K/ha and the compost provided about 784 kg P/ha and 2,128 kg K/ha, at this application rate. The pH of the papermill sludge was 7.6 and the median pH of the compost samples was 6.8 with a 6.3 to 7.5 range.

Greenhouse Pots - Herbage Yields

Yields of herbage harvested 60 days after seeding were progressively higher with each added increment of the papermill

Table 1.--Characteristics of spoils collected from two locations in the Wayne-Hoosier National Forest in southeastern OH.

Spoil Characteristics	Sites: Hanging Rock	Sites: Weltzheimer
Textural class	Sandy clay loam	Sandy loam
pH	4.1	3.3
Bray P_1 (ppm)	4.6 (low)	0.6 (very low)
K (ppm)[a]	27 (very low)	24 (very low)
Ca (ppm)[a]	2,907 (high)	84 (very low)
Mg (ppm)[a]	1,242 (very high)	52 (low)

[a] Concentrations of K, Ca, and Mg were measured in double acid extract. Comparative qualitative values per Environmental Protection Technology Series EPA-670/2-74-070, October 1974.

Table 2.--pH and Bray P_1 phosphorus 10 months and 5 harvests after seeding in greenhouse spoils amended with lime and fertilizer, papermill sludge, or mushroom compost.

Treatments and Rates	Hanging Rock Spoil		Weltzheimer Spoil	
	pH	Bray P_1 (ppm)	pH	Bray P_1 (ppm)
Control	5.5	22.1	3.5	4.7
Lime & fertilizer	7.2	28.7	6.4	12.2
Sludge 25[a/]	7.2	16.4	6.9	5.2
Sludge 50	7.2	10.9	7.0	6.4
Sludge 75	7.3	10.0	7.1	14.1
Compost 25	5.9	39.9	4.6	12.1
Compost 50	6.5	228.2	5.7	40.3
Compost 75	6.7	476.0	6.3	218.3
Mix 25	7.0	29.9	6.5	5.5
Mix 50	7.1	44.9	6.9	15.1
Mix 75	7.1	40.4	7.0	21.3

[a/] Rates are grams of sludge or compost added per 1,000 grams spoil (air-dry basis). Mix was half sludge and half compost.

Table 3.--Some properties of papermill sludge and mushroom compost used to amend acid spoils[a/].

Property	Papermill Sludge	Mushroom Compost
pH	7.6	6.8 (6.3 - 7.5)
N (%)	1.06	2.64
P (ppm)	1,825	7,148
K (ppm)	2,575	19,352
Ca (ppm)	197,897	66,857
Mg (ppm)	5,798	14,823
Fe (ppm)	4,425	6,183
Al (ppm)	23,026	5,273

[a/] Analyses on ovendry material.

sludge, mushroom compost, and mix of the two materials. The highest yields resulted from the high rate of the mixed organic amendments. Yields from the low rate of compost were similar to the yields from the lime plus fertilizer treatment; pots with the low rate of sludge and mix yielded less than those with lime plus fertilizer.

Cumulative yields of herbage from five harvests are shown in table 4. These yields show the same general relationship among treatments as in the first harvest. Yield of clover increased more than yield of ryegrass after the first harvest, particularly with the compost and mix treatments. Yields from the low rate of sludge were similar to the yields in the lime plus fertilizer pots. All other treatments and rates exceeded the lime plus fertilizer treatment, some by as much as 500 percent. This seemingly is a result primarily of the higher levels of N, P, and K in the organic materials, especially the compost, though other benefits of the organic materials may also contribute to better plant growth. These benefits may include lower soil temperatures, increased infiltration and retention of water, increased availability of nutrients, and better soil aeration.

Field Plots - Herbage Yields and Cover

Results in the field plots supported the results in the greenhouse pots, in that the sludge and compost amendments produced much higher yields than did lime and fertilizer (table 5). In 1983, the high rate of compost produced the highest yield of herbage followed closely by the low rate of compost and high rate of mixed materials. In 1984, the highest yield was harvested from the plots with the high rate of papermill sludge followed by the high rate of mix and high rate of compost. Average vegetative cover was visually estimated in May 1986. Cover was least on field plots treated with lime and fertilizer (70%), and greatest on plots treated with the high rate of compost (90%) and high rate of sludge-compost mix (90%). The overall vigor of vegetation also was best in the latter two treatments.

Endomycorrhizae Development

In the greenhouse study, formation of endomycorrhizae in plants was enhanced by all rates of papermill sludge additions and by the two higher rates of the sludge-compost mix (54 to 98% incidence) as

Table 4.--Cumulative herbage yields of five harvests from greenhouse pot study.

Treatments and Rates	Hanging Rock Spoil			Weltzheimer Spoil		
	Ryegrass	Clover	Total	Ryegrass	Clover	Total
	(g/pot, ovendry)					
Control	1.07	0.16	1.23	0.03	0.00	0.03
Fertilizer & lime	5.39	8.13	13.52	5.72	6.52	12.24
Sludge 25[a]	6.31	5.94	12.25	6.84	10.11	16.95
Sludge 50	11.81	15.98	27.79	12.80	17.72	30.52
Sludge 75	16.48	12.96	29.44	16.77	15.94	32.71
Compost 25	8.23	21.19	29.42	11.07	29.73	40.80
Compost 50	15.53	27.84	43.37	13.83	37.73	51.56
Compost 75	20.82	18.94	39.76	19.08	39.09	58.17
Mix 25	6.85	16.39	23.24	6.39	28.39	34.78
Mix 50	12.66	35.53	48.19	11.51	37.31	48.82
Mix 75	17.00	38.09	55.09	16.42	43.85	60.27

[a] Rates are grams of sludge or compost added per 1,000 grams spoil (air-dry basis). Mix was half sludge and half compost.

Table 5.--Herbage yields in field plots at end of 1983 and 1984 growing seasons.

Treatments	1983 (kg/ha,	1984[a] ovendry)
Compost, high rate[b]	4,633	4,902
Compost, low rate	4,239	4,651
Mix, high rate	4,208	5,003
Sludge, high rate	3,269	5,883
Mix, low rate	2,375	4,267
Sludge, low rate	2,149	3,699
Lime & fertilizer[c]	1,906	1,915

[a] Includes current year's growth and previous year's residual plant material.

[b] High rate = 112 t/ha and low rate = 76 t/ha (air-dry); Rates for mixes were 56 (high) and 38 (low) t/ha of each material.

[c] Agricultural lime at 16 t/ha; 10-10-10 fertilizer at 560 kg/ha.

compared to the modest incidence of endomycorrhizae (27 and 28%) in the lime-fertilizer treatment. In contrast, formation of endomycorrhizae was inhibited in all pots amended with mushroom compost (0 to 7% incidence)(table 6). The relatively higher levels of Bray P_1 (plant-available) phosphorus in most of the compost-treated spoils (table 2) suggest that there may have been little need for VAM fungi to function in providing P to plants, thus accounting for their low incidence or absence. The higher incidence of VAM fungi at the lower levels of P_1 in the papermill sludge and mix treatments suggests that the VAM were functional and necessary in absorbing and providing additional nutrients to plants in those pots.

In the field, the incidence of endomycorrhizae was similar (50%) in plants collected from the lime plus fertilizer plots and mixed treatment plots. However, as observed in the greenhouse study, incidence of mycorrhizal formation in the field plots was adversely affected by mushroom compost additions (30%), but was improved with the papermill sludge amendments (90%). In fact, a far greater number of spores were produced by the external mycelium growing within small clumps of sludge dispersed throughout the rhizosphere than by mycelium growing in the rhizosphere soil alone.

Though no attempt was made to characterize the effect of the intrinsic properties of the amendments on microbial development, the consistent inhibitory effect of the mushroom compost amendment on endomycorrhizae formation may be related also to factors we observed in some preliminary tests with the amendments. A water extract of mushroom compost reduced germination of red clover seed by about 50 percent as compared to an extract of papermill sludge or distilled water. Chromatographic analyses of the water extracts of mushroom compost showed the presence of phenolic compounds, whereas none were detected for comparable extracts of papermill sludge. Though it appears that the high level of plant-available phosphorus was the primary factor limiting endomycorrhizae formation in the greenhouse pots where mushroom compost was used as the sole amendment, it is also possible that phenolic compounds present in the compost may have been involved. A number of studies cited by Melhuish and Wade (1985) have implicated various phenolic compounds in ectomycorrhizae inhibition.

Comparative Costs of Amendments

Where available close to potential areas of use, papermill sludge and mushroom compost may be viable alternatives to the application of lime, fertilizer, and

Table 6.--Incidence of vesicular-arbuscular mycorrhizal fungi in roots of plants grown in greenhouse pots.

Treatments and Rates	Hanging Rock Spoil	Weltzheimer Spoil
	-------(percent)[b]	------
Lime & fertilizer	27	28
Sludge 25[a]	96	77
Sludge 50	54	84
Sludge 75	95	98
Compost 25	7	7
Compost 50	0	0
Compost 75	0	6
Mix 25	37	43
Mix 50	85	85
Mix 75	87	86

[a] Rates are grams of sludge or compost per 1,000 grams spoil (air-dry). Mix was half sludge and half compost.

[b] Number of VAM observed per 100 root segments.

mulch for amending acid mine spoils. A major consideration in their use, however, is combined costs of material, transportation, and application. At the time of this study, the cost of these materials to be applied at 336 wet t/ha (112 air-dry) was $1,344/ha for papermill sludge and $2,016/ha for mushroom compost. Additional cost for application is estimated at $320/ha. Transportation of these materials is costly. The cost of hauling sludge or compost 80 km, as in this study for example, was about $1,500/ha or about as much as the material itself. Applying lime, fertilizer, and mulch at appropriate rates costs about $1,350/ha including materials, hauling, and application. Using conditions at the field study site as a basis for comparison, total costs are about $3,164/ha or 2.3 times greater for papermill sludge and $3,836/ha or 2.8 times greater for compost than for lime, fertilizer, and mulch ($1,350/ha). Herbage yields in the field plots (1984 clipping) amended with the organic materials at the 112 t/ha rate were 2.5 to 3.0 times greater than yields in the lime-fertilizer plots (table 5). Besides the greater early productivity, the beneficial longer lasting or residual effects on plant yield and vigor may also help compensate for the higher cost of using either papermill sludge or mushroom compost, or both as amendments for acid spoil.

CONCLUSIONS

Both the papermill sludge and compost materials used in this study were effective in amending acid mine spoils and promoting growth of herbaceous vegetation. Yields of vegetation in spoils amended with these materials were several times greater than in spoils amended with lime and fertilizer only, both in greenhouse and field studies. At application rates as low as 112 air-dry t/ha, both the sludge and compost seemingly provided adequate levels of plant-available nutrients for a longer period of time than did the mineral fertilizer.

Development of endomycorrhizae was inhibited in spoils amended with mushroom compost, but enhanced in spoils amended with papermill sludge as compared to the modest development in lime-fertilizer amended spoils. High levels of plant-available phosphorus and presence of phenolic compounds in the mushroom compost are probable causes for this inhibition of endomycorrhizae formation. How this inhibition of endomycorrhizae may effect vegetational productivity over the long term was not determined from this study.

The cost of applying papermill sludge, mushroom compost, or a mixture of the two can be several times greater than applying needed rates of lime, fertilizer, and mulch. Much of this cost difference may be attributed to greater transportation costs for sludge and compost. However, in this study, yields of vegetation also were several times greater in spoils amended with sludge or compost than in lime-fertilizer amended spoils. Thus, based on herbage production, the cost to benefit ratio is similar for both the organic and mineral amendments.

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EFFECTS OF SEWAGE SLUDGE APPLICATION ON A REVEGETATED MINESOIL IN WEST VIRGINIA[1]

J. G. Skousen[2]

Abstract -- Municipal sewage sludge from Morgantown, West Virginia ("Morganite") was applied to a sparsely vegetated minesoil in Monongalia County, West Virginia to improve the vegetative cover and forage production on the site. Four rates (0, 22.4, 44.8, and 78.4 Mg/ha) of sewage sludge were surface applied to plots measuring 33 m long by 12 m wide in a completely randomized design with three replications in March 1986. Vegetation was evaluated and soil samples were collected and analyzed during May and September of 1986 and 1987. Water samples were collected from ponds which received the drainage from the treated area during 1986. As expected, grass cover and biomass increased as sludge application rates increased. Legume and weed biomass decreased as sludge rates increased. Metals (copper, lead, and zinc) contained in the sludge were found at increasing concentrations in the minesoil with heavier application rates. These metal concentrations in the minesoil, however, were not at levels which adversely affected plant growth or surface water quality.

INTRODUCTION

Approximately 5 million dry metric tons of municipal sewage sludge are produced in the United States each year. About one-half of the sludge is land applied. Sludge application on land improves the nutrient status, organic matter content, and water holding capacity of the soil (Hornick et al. 1984, Khaleel et al. 1981, Sommers 1977). Much research has been conducted on application of sewage sludge to agricultural lands, and guidelines for correct application procedures are available (Baker et al. 1985, Elliott 1986, Feliciano 1982, King 1986, Page et al. 1983, U.S. EPA 1983, 1984).

Many studies have also been conducted on application of sewage sludge to disturbed lands to aid reclamation and revegetation (Fresquez et al. 1984, Joost et al. 1987, Sopper and Kerr 1979, Sopper et al. 1982, Stroo and Jencks 1985, Topper and Sabey 1986), and guidelines for application have been written for the Northeast (Baker et al. 1985). Loomis and Hood (1984) suggest that sewage sludge may decrease the rate of pyrite oxidation and reduce the formation of acid mine drainage in minesoils. Seaker and Sopper (1984) found that application of stabilized municipal sludges can be used to successfully establish vegetation on mined lands.

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The benefits of amending soils and minesoils with sewage sludge are well-known, however, land application does present some potential hazards. Heavy metals in the sludge are normally adsorbed onto cation exchange sites or complexed in the organic fraction of soils and may be available for plant uptake (Gestring and Jerrell 1982, Korcak et al. 1979, Mahler et al. 1982, Mullins and Sommers 1986, Page 1974, Pietz et al. 1983, Valderes et al. 1983). Application of sludge to acid-producing materials or acidic minesoils is especially a potential problem due to solubilization of heavy metals and their movement into ground and surface water supplies (Hinkle 1982). This study was conducted to examine the effects of a one-time application of municipal sewage sludge from Morgantown, WV, ("Morganite") on the vegetation, minesoil, and surface water quality of a sparsely vegetated surface mine in West Virginia.

MATERIALS AND METHODS

Study Site

The study site was located on an area mined by King Knob Coal Company, 15 km southwest of Morgantown, Monongalia County, WV. Surface mining of the Waynesburg Seam of coal has been ongoing at this site since the early 1970's. Overburden associated with the Waynesburg Seam of coal is comprised of approximately 75 to 80 percent sandstone, with small amounts of siltstone, red and gray shales, and limestone (Cardwell et al. 1968). The haul-back method of contour mining was employed and equipment used during mining was typically bulldozers, front-end loaders, and trucks. Reclamation involved backfilling, topsoiling, liming (4.5 Mg/ha), fertilizing (672 kg/ha of 10-20-20), and reseeding to provide pasture and hayland. The plant species seeded were red clover (Trifolium pratense L.), tall fescue (Festuca arundinacea Schreb.), orchardgrass (Dactylis glomerata L.), and birdsfoot trefoil (Lotus corniculatus L.). Table 1 shows representative minesoil data collected near the reclaimed area in 1983.

Sludge Application

The Morgantown wastewater treatment plant uses an anaerobic secondary sewage treatment process utilizing rotating biological contacters (RCB). The destructive flood of November 1985 incapacitated the plant and necessitated the cleanout of the digestor tanks. The accumulated sludge was pumped from the digestors into tank trucks, mixed and stabilized with lime (pH 12), and hauled to the study site. Sludge was surface applied by a Terragator vehicle from McCutcheon Enterprises, Inc., Vandergrift, PA. Physical and chemical properties of the sludge before the lime was added are shown in table 2. Application rates were based on the organic N content of Digestor 2 and the amount of sludge needed to supply 336 kg N/ ha. The calculated sludge application rate was 78.4 dry Mg/ha, or 522.7 Mg/ha of material with 15 percent solids.

Table 1.--Representative minesoil data collected near the King Knob site where municipal sewage sludge from Morgantown, WV was surface applied (Adamo 1986).

Minesoil Classification: Typic Udorthents, loamy-skeletal, mixed, non-acid, mesic
Surface textures: sandy loam, loam, clay loam
Bulk density: 1.2 to 1.5 Mg/m^3
Water Retention (33 to 1,500 kPa): 7 to 10 percent

Depth (cm)	pH[1]	N	O.M.	CEC	K	Ca	Mg	P	Fe	Mn	Zn	Cu
		-----%----		-----cmol (+)/kg--------				-----------ug/g--------------				
0-10	7.2[2]	0.20	4.5	27.6	0.4	20.2	1.9	12.5	51.4	17.2	2.6	3.4
11-20	6.9	0.13	3.1	25.6	0.3	17.6	2.1	9.9	71.7	21.9	2.4	4.8
21-30	6.6	0.11	2.6	23.3	0.2	15.8	1.8	8.9	64.6	26.5	2.0	3.4

[1] Soil chemical analyses were conducted by the same methods as described in the text.

[2] Values are the means of eight sample replicates.

Table 2.--Physical and chemical properties of municipal sewage sludge from Morgantown, WV[1].

	Solids	Org N	NH_4-N	Total N	P	K	Ca	Mg
	%							
Digestor 1	15[2]	2.6	0.8	3.4	1.5	0.4	3.6	0.2
Digestor 2	16	2.1	1.1	3.2	1.6	0.5	2.6	0.1

	pH	Cu	Cd	Zn	Ni	Pb	Cr
		ug/g					
Digestor 1	7.3	444	9	1000	52	67	275
Digestor 2	7.7	349	9	799	48	58	308

[1] Analyzed by the Ohio Agricultural Research and Development Center, Research-Extension Analytical Laboratory, Wooster, OH.

[2] Values are the means of five samples from each digestor.

A level 0.5-ha area was chosen on the King Knob mine site and divided into twelve experimental plots measuring 12 m wide by 33 m long. One of four sludge application rates with three replications per treatment were randomly assigned to one of the twelve plots. The rates were 0, 22.4, 44.8, and 78.4 Mg/ha calculated on a dry weight basis. The sludge was applied in March 1986 and was not incorporated into the soil. Also, sewage sludge was applied to three, 2-ha areas surrounding the experimental plots.

Sampling Methods and Analysis

In each experimental plot, five randomly placed quadrats measuring 50 cm by 50 cm (0.25 m^2) were used for vegetation sampling. Total plant cover, bare ground, and litter cover were visually estimated in each quadrat. Plant species in the quadrat were identified and their cover estimated. The aboveground biomass in each quadrat was clipped at ground level; separated into grass, legume, and weed components; and placed in paper bags. The bags were taken to the laboratory, dried in a forced-air convection oven at 60°C for 48 hrs, and weighed to determine dry weight.

Minesoil samples were taken to a depth of 15 cm at each quadrat and composited into one sample for each plot. Samples were analyzed for pH using a 1:1 soil:water suspension, and organic matter by acid dichromate digestion (Soil Survey Staff 1984). Cation exchange capacity (CEC), K, Ca, and Mg were determined by ammonium acetate extraction (Soil Survey Staff 1984). Micronutrients and metals (Fe, Mn, Cu, Zn, Cd, Pb) were extracted with diethylenetriaminepentaacetic acid (DTPA) (Lindsay and Norvell 1978). Exchangeable and nonexchangeable H and Al were determined by 1N KCl extraction (Soil Survey Staff 1984). Total N was determined by the Kjeldahl method (Soil Survey Staff 1984), and available P was determined using sodium bicarbonate (Olsen et al. 1954). Vegetation and soil samples were collected in May and September of 1986 and 1987.

Vegetation and soil data were analyzed by analysis of variance and treatment means were separated by Duncan's multiple range test with computer facilities at West Virginia University.

Three water samples were collected from three ponds that receive drainage from the entire 6.5-ha study site. Samples were taken in March (before sludge application), July, and September of 1986 and analyzed by the WV Department of Natural Resources Water Resources Laboratory.

RESULTS AND DISCUSSION

Surface application of sewage sludge onto the vegetation smothered the vegetation for several months. Total cover and plant biomass were decreased as a result of heavy sludge application (table 3). However, after six months, it was evident that nutrients in the sludge increased cover and grass aboveground biomass. Legume biomass and number of legume species were decreased as sludge rates increased in September 1986 because increased nutrient levels in the minesoil caused increased grass growth and competition. Weed biomass increased with increased sludge rates in September 1986, probably because of the large weed seed bank in the sludge. Weed seeds are better suited to

Table 3.--Vegetation characteristics of a reclaimed surface mine after application of three rates of municipal sewage sludge from Morgantown, WV, in May and September 1986.

Sludge Rate (Mg/ha)	Total Cover (%)	Grass Biomass (g)	Legume Biomass (g)	Weed Biomass (g)	Grass Species (Number)	Legume Species (Number)	Weed Species (Number)
				MAY 1986			
0	59 ab[1]	13 a	4 a	.4 a	1.8 a	1.0 a	0.6 a
22.4	68 a	13 a	4 a	.4 a	1.6 a	1.1 a	0.8 a
44.8	53 ab	10 ab	7 a	.2 a	1.0 b	1.0 a	0.9 a
78.4	42 b	7 b	2 a	.2 a	1.1 b	0.5 b	1.2 a
				SEPTEMBER 1986			
0	90 b	68 b	30 a	18 b	1.9 a	1.2 a	1.2 b
22.4	91 b	56 b	13 b	31 ab	1.5 a	1.0 ab	2.1 a
44.8	96 a	88 ab	10 b	59 a	1.7 a	0.7 b	1.9 a
78.4	97 a	105 a	1 c	65 a	1.7 a	0.3 c	2.6 a

[1] Values within columns of different dates with the same letter are not significantly different at $p < 0.05$.

germinate under harsh conditions created by the surface application of sludge.

Sludge application continued to influence the vegetation on the site through 1987 (table 4). Total cover was significantly higher on sludge-treated plots than on control plots and grass biomass increased with increasing sludge rates. Compared to control plots, legume biomass and number of species were still lower on the two heaviest sludge application plots after two growing seasons. Weed biomass during the second growing season was reduced to control levels.

Table 4.--Vegetation characteristics of a reclaimed surface mine after application of three rates of municipal sewage sludge from Morgantown, WV, in May and September 1987.

Sludge Rate (Mg/ha)	Total Cover (%)	Grass Biomass (g)	Legume Biomass (g)	Weed Biomass (g)	Grass Species (Number)	Legume Species (Number)	Weed Species (Number)
				MAY 1987			
0	60 c[1]	72 c	8 a	.2 a	1.9 a	1.0 a	0.6 a
22.4	77 b	126 b	5 ab	.2 a	1.6 a	0.9 a	0.2 a
44.8	84 b	150 b	2 bc	.2 a	1.7 a	0.6 ab	0.3 a
78.4	95 a	223 a	1 c	.3 a	1.7 a	0.4 b	0.7 a
				SEPTEMBER 1987			
0	95 b	82 b	5 b	3 a	1.1 a	0.9 a	1.3 a
22.4	98 a	124 ab	8 a	2 a	1.1 a	0.9 a	0.3 b
44.8	98 a	146 ab	2 c	4 a	1.1 a	0.3 b	0.8 ab
78.4	98 a	291 a	1 c	6 a	1.0 a	0.3 b	0.9 ab

[1] Values within columns of different dates with the same letter are not significantly different at $p < 0.05$.

Soil analyses revealed that minesoil pH did not appear to be influenced by sludge application (tables 5 and 6). The pH of sludge-treated plots was never significantly different from the control plots but was lower than the pH data initially reported in Table 2. Lime was surface-applied and incorporated several months prior to the 1982 minesoil sampling and, to my knowledge, no more lime has been applied since 1982 . Organic matter content of treated minesoils shows an increasing trend over time, but the values for sludge-treated plots are again not

Table 5.--Chemical characteristics of minesoil with four rates of surface-applied sewage sludge from Morgantown, WV, in May and September 1986.

Sludge Rate (Mg/ha)	pH	O.M.	K	Ca	Mg	H	Al	Fe	Mn	Zn	Cu	Pb
		%	cmol (+)/kg					ug/g				
						MAY 1986						
0	4.7a[1]	1.6a	.9a	7.9a	.7a	.65a	.40a	101a	193a	1.4b	1.0b	4.5b
22.4	4.9a	2.0a	.9a	12.2a	.9a	.25a	.46a	101a	213a	3.6a	2.2a	5.6ab
44.8	5.0a	1.9a	.9a	14.6a	.8a	.42a	.23a	105a	229a	4.7a	2.6a	6.2a
78.4	4.8a	1.9a	.8a	10.0a	.7a	.59a	.33a	117a	204a	5.3a	2.8a	6.8a
						SEPTEMBER 1986						
0	5.0a	1.8a	.9a	7.4a	.7a	.60a	.36a	108b	241a	1.6c	1.1c	4.6b
22.4	5.3a	2.2a	.8a	12.1a	.8a	.55a	.13a	118ab	282a	4.8b	2.4b	4.4b
44.8	5.1a	2.2a	.9a	11.8a	.9a	.70a	.26a	125ab	245a	5.3b	2.4b	5.1ab
78.4	4.9a	2.1a	.9a	12.2a	.9a	.66a	.40a	138a	236a	8.5a	3.6a	5.6a

[1] Values within columns of different dates with the same letter are not significantly different at $p < 0.05$.

Table 6.--Chemical characteristics of minesoil with four rates of surface-applied sewage sewage sludge from Morgantown, WV, in May and September 1987.

Sludge Rate (Mg/ha)	pH	O.M	K	Ca	Mg	H	Al	Fe	Mn	Zn	Cu	Pb
		%	cmol (+)/g					ug/g				
						MAY 1987						
0	5.6a[1]	1.9a	.8a	9.6a	.7a	.14a	.16a	96a	235a	1.5c	0.7b	5.5a
22.4	5.8a	2.2a	.8a	15.3a	.9a	.59a	.09a	83a	304a	6.5b	2.6ab	6.2a
44.8	5.9a	2.5a	.9a	23.2a	1.0a	.43a	.29a	116a	337a	7.7ab	4.2a	6.4a
78.4	5.9a	2.2a	.9a	16.7a	.8a	.56a	.26a	157a	319a	9.2a	4.4a	5.6a
						SEPTEMBER 1987						
0	4.6a	1.4b	1.2a	6.6a	1.1a	.82a	1.87a	179b	216a	1.3b	2.2b	1.2b
22.4	5.1a	2.5a	.9a	13.4a	1.1a	.43a	.33b	211ab	207a	2.4b	4.4a	1.6ab
44.8	5.4a	2.8a	1.2a	19.5a	1.2a	1.20a	.47b	222ab	184a	4.2a	4.4a	1.9a
78.4	4.9a	2.7a	.9a	15.0a	1.3a	.54a	.93b	254a	185a	5.7a	5.3a	2.0a

[1] Values within columns of different dates with the same letter are not significantly different at $p < 0.05$.

significantly higher than control plots. Most studies report an increase in organic matter content in soils after treatment with an organic waste material (see Khaleel et al. 1981). In plots receiving the heaviest sludge application, iron concentrations were significantly higher only during the September sampling dates of both years. Zinc, copper, and lead were all signficantly higher in treated plots than in control plots at all sampling dates. Loading rates of Zn, Cu, and Pb at 78 Mg/ha of sludge were 34.8, 78.4, and 5.3 kg/ha, respectively. Cadmium was added at a rate of 0.7 kg/ha, but the equipment used for analysis did not detect any Cd in sludge-treated minesoils.

Analyses were not conducted to determine metal concentrations in forages growing on the site, but no visual symptoms of stress or reduced growth of plants in treated minesoils were apparent. Pietz et al. (1983) reported that applications of 258 Mg/ha of sewage sludge increased Cd, Cu, Ni, and Zn concentrations in a calcareous strip-mine spoil and uptake of these metals by corn also increased. Similar findings are reported by Korcak et al. (1979), Valdares et al. (1983), Gestring and Jarrell (1982), and Mullins and Sommers (1986).

Water samples collected from three ponds which received the drainage from the entire 6.5-ha sludge-treated area showed few differences from the water collected before the sludge was applied (table 7).

Table 7.--Chemical characteristics of surface water collected from ponds which received the drainage from sludge-treated minesoils in West Virginia.

	DATE[1]		
Characteristic	Mar 86	May 86	Sept 86
pH	7.3	6.9	7.5
NO_3-N (mg/l)	3.7	3.0	2.0
Cr (ug/l)	4.0	7.3	8.7
Zn (ug/l)	226.0	157.3	197.3
Cu (ug/l)	12.3	8.3	10.0
Cd (ug/l)	1.3	1.2	1.0
Ni (ug/l)	178.0	118.3	215.3
Pb (ug/l)	24.0	41.7	38.0
Al (ug/l)	2506.7	586.7	841.0

[1] March 86 sampling date was approximately 1 week prior to sludge application, while May and September were 2 months and 6 months after application, respectively.

[2] Values are the average of nine samples.

Chromium and lead concentrations appear to have increased since sludge application, but caused no concern to the Department of Natural Resources, who therefore did not collect and analyze water samples from the site after September 1986. Hinesly et al. (1984) found higher Zn, Cu, Cd, and Cr concentrations in water from sludge-treated lysimeters.

SUMMARY

A one-time application of municipal sewage sludge from Morgantown, WV significantly improved the plant cover and biomass produced on the site for two growing seasons following application. However, pH and macronutrient levels were not influenced or only slightly influenced by sludge application. Heavy metals contained in the sludge were found at increasing levels in the treated minesoils, but the metals did not appear to affect vegetation or move into surface water supplies.

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RECLAMATION SUCCESS AT AN ABANDONED DEEP COAL MINE SITE NEAR STAUNTON, ILLINOIS[1]

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Abstract.--Reclamation activities began in 1976 on the 13.8-ha site of an abandoned deep coal mine near Staunton, IL. An area of about 9.3 ha was severely eroded, devoid of vegetation, and received little use by wildlife. Reclamation procedures included grading and recontouring the coal refuse (gob) pile and slurry area, covering exposed refuse material with soil, liming the soil, seeding with selected plant species, and creating a pond to receive runoff from the site. To evaluate reclamation, soil depth (30 and 60 cm) and liming rate (112 and 224 t $CaCO_3$ equivalent/ha) were experimentally manipulated in plots on top of the gob pile. Studies were conducted annually from 1977 to 1982 and again in 1987. After reclamation activities were completed, vegetation quickly became established over most of the site, except for some areas on the slopes of the gob pile. Vegetative cover was greatest on plots with 60 cm of soil and a 224 t/ha liming rate. Soil depth appeared to be more important than liming rate in determining vegetative cover. Wildlife used the site following reclamation, especially those areas with the greatest habitat diversity.

INTRODUCTION

The success of reclamation activities at an abandoned deep coal mine was evaluated approximately 10 years after initial reclamation efforts were made. Reclamation began in 1976 at the abandoned Consolidated Coal Company Mine No. 14 in Macoupin County, IL, near the town of Staunton (Jastrow et al. 1984). The site covered 13.8 ha and included a 9.3-ha area that had been affected by past mining and coal refuse disposal operations that had taken place from 1904-1921. The steep, 25-m-high refuse (gob) pile covered 1.8 ha and was highly eroded and devoid of vegetation. Vegetation was also lacking from areas that received acid runoff from the pile. Most drainage from the gob pile was impounded during mine operation behind a dam that had been constructed across a ravine near the edge of the property. After mining ceased, this impoundment continued to receive runoff and sediment from the gob pile, and sediment accumulated to a depth of approximately 9 m. In the early 1940's, the dam was breached and the 4.5-ha slurry area began to erode and contribute acidic runoff and sediment to nearby Cahokia Creek. This slurry area was also largely devoid of vegetation when reclamation activities began in 1976.

Reclamation work began with the excavation of a borrow pit adjacent to the gob pile (Jastrow et al. 1984). From the borrow pit, B and C soil horizon material (weathered Illinoian glacial till) was removed and stockpiled for use as cover material. Material from the gob pile was used to fill the borrow pit, and the pile was graded. The recontoured pile was one fifth of its original height and covered an area more than twice its original size (fig. 1). The remainder of the area was also graded, and a new 0.5-ha sediment retention pond was created in the slurry area. Neutralizing agents were applied to the refuse and slurry areas at 170 t/ha $CaCo_3$ equivalent and incorporated to a depth of 15 cm using a disk harrow. Agricultural limestone was used as a neutralizing agent on the gob pile and "Code L Alkali", a fine-textured mixture of calcium oxide and calcium carbonate, was used on the slurry area to stabilize as well as neutralize the fines. Stockpiled soil material was then placed to a depth of 30 cm over the gob pile and slurry areas. The top of the gob pile was graded flat to prevent runoff and erosion of cover material from the area. Agricultural limestone (11.2 t/ha 75% $CaCO_3$ equivalent) was applied to the entire site and incorporated to a depth of 10 cm. Next, the site was fertilized with nitrogen, phosphoric acid, and potash (135 kg/ha each) and, in April 1977, seeded with a mixture of legumes and grasses (table 1). Bare areas totaling 2 ha were reseeded in August and September 1981 with additional species.

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Table 1.-- Seed mixture used to revegetate the Staunton Reclamation Site in April 1977 (Jastrow et al. 1984).

Species	Application Rate (kg/ha)
Reed canarygrass (*Phalaris arundinacea*)	11.2
Tall fescue (*Festuca arundinacea* cv. Kentucky-31)	16.8
Birdsfoot trefoil (*Lotus corniculatus*)	13.5
Ladino clover (*Trifolium repens*)	5.6
Cereal rye (*Secale cereale*)	22.4

Sixteen revegetation research plots were established on 0.73 ha of the top of the gob pile and were prepared and treated in a different manner from that described in the preceding paragraph (Jastrow et al. 1984). A factorial experimental design was used to determine the effects of four different soil cover material depths (0, 15, 30, and 60 cm) and two liming rates (112 and 224 t/ha) on revegetation of the limed gob pile. Two replicate plots (21.3 by 21.3 m) were used for each treatment combination. Plots were seeded with species listed in table 2. Due to difficulties in soil cover application, the 15-cm soil depth plots actually had 30 cm of soil cover and were, therefore, considered with other 30-cm plots in the analysis. Extremely poor plant establishment occurred on the 0-cm soil depth plots, and these were later covered with soil material and seeded; these plots were eliminated from the analysis.

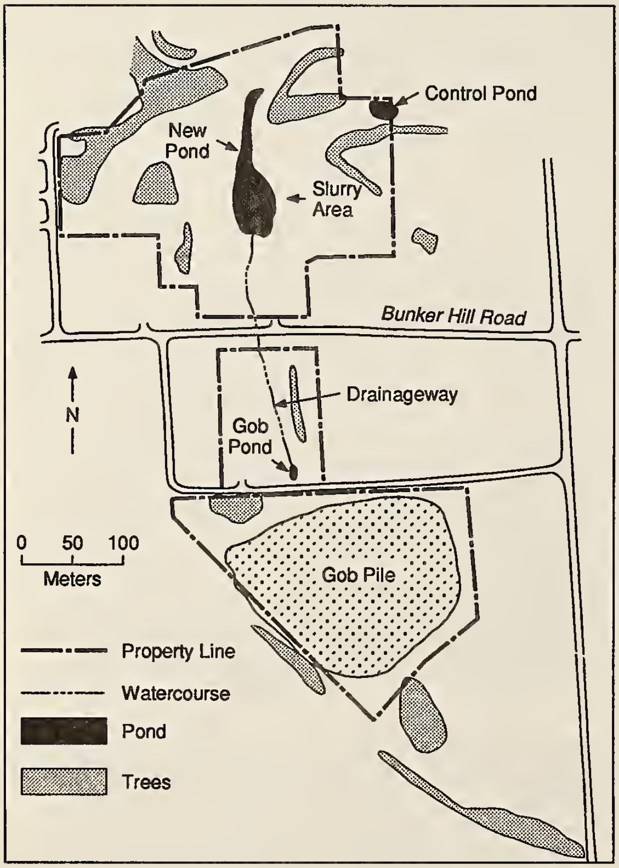

Figure 1.--Staunton Reclamation Site.

The results of research to determine the success of reclamation activities in promoting revegetation and wildlife use of the site from 1977 to 1981 has been reported elsewhere (Pentecost and Stupka 1979; Jastrow et al. 1984). Most of the results indicated that reclamation had been a success on these accounts although some areas of the gob pile had begun to develop acid seeps by 1981 (Jastrow et al. 1984). The objective of the current research effort was to evaluate the site 10 years after initial reclamation activities took place.

MATERIALS AND METHODS

Experimental Revegetation Plots

Revegetation was evaluated in research plots with 30-cm and 60-cm soil cover depths in August 1977, June and August of 1978 through 1981, June 1982, and July 1987. Within each plot, five parallel, evenly spaced, east-west transects were

Table 2.--Seed mixture used on revegetation research plots on the Staunton Reclamation Site, April 1977 (Jastrow et al. 1984).

Species	Application Rate (kg/ha)
Little bluestem (*Andropogon scoparius* cv. Camper)	6.3
Smooth brome (*Bromus inermis* cv. Lincoln)	8.3
Orchardgrass (*Dactylis glomerata* cv. Potomac)	8.3
Tall fescue (*Festuca arundinacea* cv. Kentucky-31)	12.2
Deertongue (*Panicum clandestinum* cv. Tioga)	4.4
Switchgrass (*Panicum virgatum* cv. Blackwell)	11.1
Reed canarygrass (*Phalaris arundinacea*)	6.6
Birdsfoot trefoil (*Lotus corniculatus*)	8.3

established. The point-intercept method was used along these transects to estimate plant cover (Mueller-Dombois and Ellenberg 1974). Four sampling sites were chosen at random within each transect and areal cover was estimated with a 1-m-tall, 10-pin point frame with pins 10 cm apart. Three transects in each plot were used in 1987 to estimate areal cover. Areal cover for each species in a plot was estimated by determining the percentage of pins that were touched by that species during a sampling period. Thus, if a species touched 100 of 200 pins in a plot (200 pins = 10 pins/frame x 4 frames/transect x 5 transects/plot), the estimated areal cover for that species was 50%. Total cover was estimated in a similar fashion, but the percentage of pins in contact with any plant was used to calculate cover. Data from 1977 to 1981 were reported in Jastrow et al. (1984). The entire data set from 1977 through 1987 is re-evaluated in this report to determine the long-term effects of the soil treatments used.

Wildlife Studies

In 1987 surveys of bird and mammal use of the site were conducted over a five-day period. Three areas were surveyed for birds--the gob pile, slurry area, and drainageway between the gob and slurry areas (fig. 1). Both qualitative (species lists) and quantitative (relative numbers and use) data were collected for each of these areas. All bird and mammal (including tracks) species seen in these areas during the course of field work on the site were recorded to develop a list of species using the site in 1987. In addition, systematic counts of birds were made during morning hours (0530 to 0830 CST) while walking slowly through each area. Records were kept of the amount of time spent in each area (an estimate of effort expended) and the number of each species seen on or flying over each area. Small mammals were live-trapped on three consecutive nights using collapsible Sherman live traps (9 cm by 9 cm by 23 cm). Rectangular trap grids were established on top of the gob pile (4 by 5 grid), at the base of the gob pile (4 by 5 grid), and in the slurry area (4 by 6 grid). Distances between traps on the gob pile top, slurry area, and gob pile base were 21 m, 10m, and 10m, respectively. Traps were baited with a mixture of peanut butter and rolled oats each evening near dusk and checked the following morning. Trapped individuals were identified, sexed, and toe-clipped for later identification. The results of these surveys and similar wildlife studies conducted on the site during the summer months of 1977 and 1978 (Pentecost and Stupka 1979) were compared to determine if changes in species use had occurred since initial reclamation efforts were made.

RESULTS AND DISCUSSION

In general, vegetative cover over the entire site was well established in 1987. Excellent cover was attained in the slurry area and areas with at least 30 cm of soil cover on top of the gob pile. Only areas where acidic gob material was exposed due to erosion of slopes or where acidic drainage occurred were devoid of vegetation. These areas were concentrated on the slopes of the gob pile (especially the south slope) and in the drainage area between the gob pile and the slurry area pond. Erosion problems and lower cover in these areas were noted in 1978 (Jastrow et al. 1984). As water penetrates the soil cover material, it flows over the relatively impenetrable gob material and acidifies, and then discharges near the bottoms of slopes (Drake 1983b). The acidic water issuing from these seeps results in the death of nearby plants and subsequent erosion of the exposed soil. Because of the extremely low pH (approximately 2.5; Vinikour et al., elsewhere in these proceedings) of water in the drainageway and the slurry area pond, no emergent vegetation was present in 1987 despite the early establishment of cattails after initial reclamation activities were completed in 1976. Most cover present on the site was provided by species that were originally planted, but several other plants including common reed (*Phragmites communis*) and several tree species (mostly cottonwood, *Populus deltoides*; willow, *Salix* sp.; and black locust, *Robinia pseudoacacia*) had become established, especially in the slurry area.

Experimental Revegetation Plots

Vegetative cover was high (mean of 75% or more) for all treatments (fig. 2). However, differences among years and treatment (soil depth and liming rate) were apparent (table 3). Areal cover in the first year following reclamation was high (> 90%) in all experimental plots. Differences between treatments were apparent in subsequent years, especially in the drought years of 1979 and 1980. Soil depth appeared to have a greater effect on vegetative cover than did lime application rate (table 3; fig. 2). Plots with 60 cm of soil cover had the highest percentage of plant cover; the amount of lime used did not affect cover in these plots. For plots with 30 cm of soil, lime rate was important; plots with 224 t/ha of lime had greater plant cover than did plots with 112 t/ha.

Soil depth has been shown in other studies to affect the growth and establishment of plants on acidic mine refuse (McGinnies and Nicholas 1980; Drake 1983a, 1986). Increased soil depth serves to increase the distance between the acidic gob material and the roots of plants and it also increases the amount of water available to plants. This latter point was made especially apparent during the drought years of 1979 and 1980 when plant cover on 30-cm-deep soil was considerably less than that on 60-cm-deep soil. Although the amount of lime applied to the plots had less of an effect than soil depth on plant growth, increased lime did serve to promote vegetative cover. The effect of lime was more apparent in 30-cm-deep soil than in 60-cm soil presumably because of the reduced distance between plant roots and the acidic gob material in the 30-cm soil and thus, the greater need for neutralizing agents.

Invading (nonplanted) species dominated revegetation plots only during the first year, and were almost completely replaced by species that were planted in 1976 (fig. 2). Drake (1983a) also reported that foxtail (*Setaria* sp.) was dominant

Table 3.--Analysis of variance for the effects of lime application rate, soil depth, and year on percent areal cover of vegetation on the Staunton Reclamation Site.

Source	d.f	F	P > F	
Lime Rate	1	4.7	0.04	*
Soil Depth	1	27.0	0.0001	*
Year	6	61.4	0.0001	*
Lime x Depth	1	3.6	0.06	
Lime x Year	6	0.2	0.97	
Depth x Year	6	4.7	0.001	*
Lime x Depth x Year	6	0.2	0.98	

*Significance at the 0.05 level.

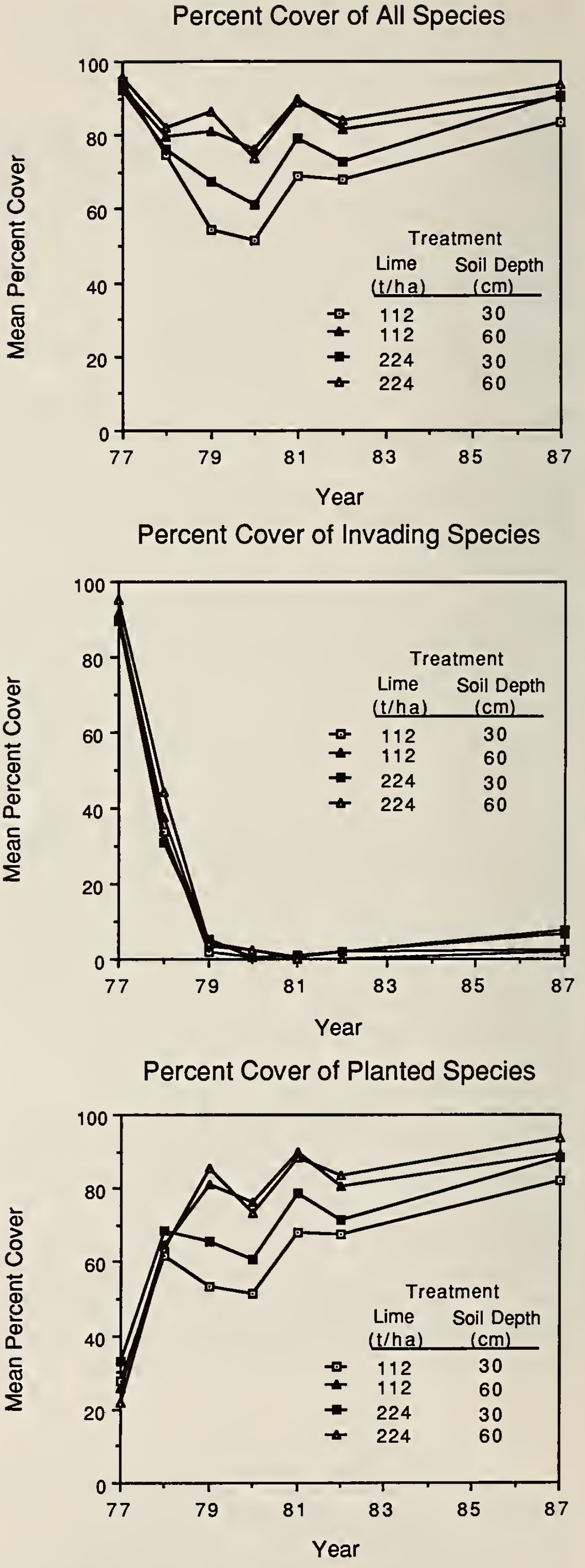

Figure 2.--Percent areal cover of vegetation according to soil depth and lime application rate on the Staunton Reclamation Site, 1977 to 1987.

during the first years following reclamation, but was rapidly replaced by perennial grasses. Representation of the planted species varied through time, and some species were almost completely eliminated (deertongue, orchardgrass, reed canarygrass). Switchgrass and little bluestem, both relatively drought-tolerant, were most abundant in 1987. These two species were found to be particularly suitable for the revegetation of acid mine spoils in Iowa (Drake 1983b).

Wildlife Studies

Thirty four species of birds were observed on the site during field work conducted in July 1987 (table 4). The most common species included the European starling, house sparrow, barn swallow, chimney swift, and eastern meadowlark. Species observed on the site were similar to those recorded for adjacent areas in 1977 and 1978 (Pentecost and Stupka 1979).

The total number of birds observed per hour of survey was greatest for the drainage area and least for the gob pile, although values were relatively similar (table 4). Differences between areas can be explained by differences in the availability of different habitats and ecotones (edges) within each study area. The drainage area was fairly narrow and bordered on one side by trees and on the other by an overgrown fencerow. The slurry area was predominantly an oldfield community, but there were stands of small trees along several drainages within the area that increased habitat diversity. The slurry area was surrounded by oldfield and forest communities. If the pond created in the slurry area had not acidified and retained some emergent vegetation, bird numbers and diversity in this area would probably have been higher. The gob pile, dominated by a grassland community, had little habitat diversity; it was approximately rectangular in shape with forest and oldfield along its borders.

Table 4.--Bird species seen on the gob pile, slurry area, and drainage area of the Staunton Reclamation Site, July 1987. Numbers presented are birds observed per hour of surveying.

	Survey Area		
Species	Gob	Slurry	Drainage
Bobwhite (*Colinus virginianus*)	r	2.3	1.9
Killdeer (*Charadrius vociferus*)	4.2	4.5	0
Mourning Dove (*Zenaidura macroura*)	1.4	4.5	1.9
Chimney Swift (*Chaetura pelagica*)	12.7	16.5	13.1
Common Flicker (*Colaptes auratus*)	0.7	r	0
Downy Woodpecker (*Picoides pubescens*)	0	r	0
Red-headed Woodpecker (*Melanerpes erythrocephalus*)	0	0.8	0
Eastern Kingbird (*Tyrannus tyrannus*)	0	0.8	0
Eastern Phoebe (*Sayornis phoebe*)	r	0	0
Eastern Wood Pewee (*Contopus virens*)	0	0.8	0
Barn Swallow (*Hirundo rustica*)	12.7	3.0	13.1
Rough-winged Swallow (*Stelgidopteryx ruficollis*)	r	0	0
Purple Martin (*Progne subis*)	4.9	2.3	1.9
Carolina Chickadee (*Parus carolinensis*)	0.7	1.5	0
Tufted Titmouse (*Parus bicolor*)	1.4	0	0
White-breasted Nuthatch (*Sitta carolinensis*)	0	0.8	0
House Wren (*Troglodytes aedon*)	0.7	0	0
Northern Mockingbird (*Mimus polyglottus*)	0	r	0
Brown Thrasher (*Toxostoma rufum*)	1.4	0	1.9
American Robin (*Turdus migratorius*)	7.1	3.0	5.6
European Starling (*Sturnus vulgarus*)	10.6	24.0	28.1
Warbling Vireo (*Vireo gilvus*)	1.4	1.5	0
Common Yellowthroat (*Geothlypis trichas*)	0	2.3	1.9
Yellow-breasted Chat (*Icteria virens*)	r	0	0
House Sparrow (*Passer domesticus*)	10.6	12.8	18.8
Eastern Meadowlark (*Sturnella magna*)	10.6	6.8	1.9
Red-winged Blackbird (*Agelaius phoeniceus*)	0.7	6.8	7.5
Common Grackle (*Quiscalus quiscula*)	0.7	1.5	0
Brown-headed Cowbird (*Molothrus ater*)	0.7	0	0
Northern Cardinal (*Richmondena cardinalis*)	0.7	0	5.6
Indigo Bunting (*Passerina cyanea*)	0	0	1.9
American Goldfinch (*Spinus tristis*)	0.7	0	0
Field Sparrow (*Spizella pusilla*)	1.4	0	0
Song Sparrow (*Melospiza melodia*)	0	0	5.6
Total Birds Observed/hr	86.1	96.0	110.6

r = indicates that the species was observed, but not counted during the surveys.

Evidence of nesting was observed for two species although the surveys were conducted outside of the nesting season and an intensive search for nests was not conducted. A covey of bobwhite consisting of mother and several chicks were flushed occasionally while doing field work in the slurry area. An unhatched killdeer egg was seen on an exposed patch of soil on the top of the gob pile. Singing males of a variety of species were observed and many of the species probably nest on the site or in the vicinity.

Trapping, direct observation, and observation of sign in July 1987 resulted in the recording of seven species of mammals for the site (table 5). The prairie vole was abundant on the site and had a higher density in the slurry area than on the gob pile (4 captures in the two 20-trap grids on the gob pile; 12 captures in the 24-trap grid in the slurry area). The house mouse was the only other species captured in the live traps (one captured in slurry area). The deer mouse (*Peromyscus maniculatus*) was not captured in 1987 although this species is often abundant on abandoned mined lands (Sly 1976; Hansen and Warnock 1978). Hanson and Warnock (1978) found an inverse relationship between the abundance of the deer mouse and the abundance of grasses; the dense grass cover present in all areas of the site may not have provided suitable habitat for this species. Of the species recorded in 1987, only the gray squirrel had not been recorded in 1977 and 1978. The muskrat (*Ondatra zibethica*) was not seen in 1987 despite its being recorded in previous years. This can undoubtedly be attributed to the acidification of the pond and the subsequent die-off of emergent vegetation (Perry 1982; Allen and Hoffman 1984).

Table 5.--Mammals recorded on the Staunton Reclamation Site, July 1987.

Opossum (*Didelphis marsupialis*)
Raccoon (*Procyon lotor*)
Cottontail (*Sylvilagus floridanus*)
Gray Squirrel (*Sciurus carolinensis*)
House Mouse (*Mus musculus*)
Prairie Vole (*Microtus ochrogaster*)
White-tailed Deer (*Odocoileus virginianus*)

SUMMARY AND CONCLUSIONS

The results of the experimental revegetation studies indicate that soil depth is more important than the rate of lime application in determining the amount of vegetative cover on acidic gob material. It appears that 60 cm of soil is adequate for establishing cover of 80% or more. Once initial reclamation practices are complete and the area is seeded with perennial grasses, especially drought-tolerant species, the community can become self-sustaining. The low-relief slurry area on the site had excellent plant growth and essentially 100% cover with only 30 cm of soil cover.

Seepage of acidic water from the gob material and erosion of areas devoid of vegetation is one unresolved issue that needs further consideration. Drake (1983b) suggests several designs for directing acid throughflow that could prevent plant loss and erosion. The type of lime material may also be important in preventing acidification of the soil cover. On the gob pile, agricultural limestone was used. This material was fairly coarse and the large chunks became coated with iron precipitates, thus limiting its neutralizing capabilities. A finer textured neutralizing material is recommended.

Despite the problems in establishing complete vegetative cover and preventing erosion, the site was used by a variety of wildlife species. Habitat diversity appears to be the most important factor at this point in determining the use of the site by wildlife. A diverse wildife population can be obtained by properly planning the area for a variety of habitat types.

ACKNOWLEDGMENTS

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SUPPLY AND TURNOVER OF N, P, AND K IN RECLAIMED COAL MINE WASTE IN SCOTLAND

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Abstract. Field trials were established in 1980 on coal mine spoil at Baads Colliery, West Lothian, to assess the effect of various organic treatments on nitrogen, phosphorus, and potassium levels. Chicken manure, sewage sludge, a seaweed-based soil conditioner, and peat were applied to limed and unlimed plots. Chicken manure and sewage sludge supplied large amounts of nitrogen and phosphorus initially, but this effect did not last beyond the sixth year after establishment. Carbon and nitrogen turnover showed little variation between treatments. The ratio of C:N mineralized was high in all cases, suggesting a deficiency of nitrogen. Spoil and herbage analyses suggested a deficiency of phosphate, but no response to added P was obtained. A survey of sites in Central Scotland was made to assess which parts of the nitrogen cycle function in coal mine spoil. Spoils of widely varying properties were sampled and showed high rates of carbon turnover, but little nitrogen mineralization. Nitrification occurred only on sites of pH > 5.5, but was not measured on all sites with these pH values, presumably due to the absence of nitrifying bacteria. Ammonium fixation by clay minerals was high on some sites. Extractable inorganic nitrogen values were generally low.

INTRODUCTION

A major long-term factor to be considered when reclaiming coal mine waste is the supply of sufficient amounts of nutrients for plant requirements. Fertilizers are routinely added at seeding and provide immediate benefit. If a site is subsequently managed for agricultural or recreational use, the nutritional level may be maintained by further applications of fertilizers. Very often, however, reclamation does not have a specific aim, other than cosmetic purposes, and so management ceases after the establishment period. In this case it is important to initiate nutrient cycling so that a system develops which can sustain a reasonable plant cover. The difficulty is that coal mine waste tends to be a system of low nutrient turnover, which lacks a humified organic matter component. This latter is particularly important for N and P supply.

It has generally been found that reclaimed coal mine waste is deficient in nitrogen and phosphorus, but reasonably sufficient in potassium (Fitter and Bradshaw 1974, Pulford and Duncan 1978, Bloomfield et al. 1982). Of these three macronutrients, nitrogen has undoubtedly received the greatest attention. It has been suggested that nitrogen in the waste coal and shales may be made available to plants on weathering (Cornwell and Stone 1968), and attempts have been made to characterise the various N fractions in spoil (Palmer et al. 1985). More commonly, the supply of N to plants by various treatments has been measured (Palmer and Chadwick 1985, Palmer et al. 1986), as have N transformations such as mineralization and nitrification (Williams and Cooper 1976, Reeder and Berg 1977). Bradshaw (1983) has estimated that a nitrogen capital of about 1,600 kg N/ha is required to sustain a vegetation cover. This is based on a requirement of 100 kg N/ha/annum and an organic matter decomposition rate typical of temperate soils. Broadly, two main strategies are used to supply N in sufficient amounts over the longer term, a single supply of manures at a high rate, which may also supply some P, and the use of legumes to fix atmospheric nitrogen. In this study, organic amendments were applied to a limed acid spoil to assess the long-term supply of nitrogen, phosphorus, and potassium to plants.

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MATERIALS AND METHODS

Experimental plots were set up at Baads Colliery, West Lothian, in 1980 with the following treatments, chicken manure, sewage sludge, a seaweed-based soil conditioner, peat, and no organic amendment, applied to limed (25 and 50 t/ha) and unlimed plots. All plots received 300 kg/ha of a 15:10:10 NPK compound fertilizer. Samples were taken from the plots which had received the organic amendments and 25 t/ha lime, and from the no amendment plots which had received 0 and 25 t/ha lime.

Spoil pH was measured in a 1:2.5 spoil: water suspension, using a combination pH electrode. Extractable P and K were measured in a 2.5% acetic acid extract (1:10 spoil:extractant); N, P and K contents of herbage were determined in the dried grass by Kjeldahl digestion. N and P were measured by automated colorimetric analysis, and K by flame photometry.

For C and N turnover measurements, 50g fresh spoil was incubated in a 1.5-l Kilner jar, with a beaker containing 20 cm^3 1 M NaOH. Carbon dioxide evolved was determined by the method of Jenkinson and Powlson (1976). Inorganic N was extracted with 0.5 M K_2SO_4 solution at a 1:20 spoil: solution ratio, and measured by automated colorimetric methods. For ammonium fixation and nitrification measurements, the spoils were treated with 100 mg NH_4-N/kg prior to incubation.

RESULTS AND DISCUSSION

Table 1 shows the yields of herbage for the treated plots, expressed as a percentage of the control yield in each year (100%), so that annual variations can be removed. This shows that the addition of the manure-type amendments (chicken manure and sewage sludge) resulted in much higher yields initially, but these declined so that by the seventh year there was no difference between any treatment and the controls. The peat and soil conditioner treatments gave poorer herbage yields in the first year, but thereafter these treatments behaved similarly to the controls. The N, P, and K content of the herbage did not differ greatly between treatments, but the large differences in herbage yield resulted in corresponding differences in N, P, and K in the standing crop.

Acetic acid extractable levels of P and K were measured in the spoil in 1983 and 1984 (table 2). Except for the chicken manure-treated spoil, extractable P levels were very low. This agrees with the general findings of previous studies that extractable P is low in colliery spoil. Palmer (1978) used a number of standard P extractants on spoil from the Yorkshire coalfield, and found that the levels of P removed were too close to zero to be of value. Fitter et al. (1974) reported a mean of 5.5 mg P/kg for bicarbonate-extractable P in Lancashire spoil. Using spoil from the Scottish coalfield, Pulford (1976) could find no acetic acid-extractable P in acid spoil. Lister (1987), using the Bray method (0.1 M HCl + 0.05 M NH_4F) also on Scottish spoil, found that extractable P ranged from zero to 19.3 mg P/kg, with a mean of 6.2 mg P/kg. The value of such extractable P figures in coal spoil is questionable however, due to the ability of many spoils to adsorb large amounts of phosphate, particularly under acid conditions (Pulford and Duncan 1975). A mean value for maximum P adsorption of 1.5 mg P/g was measured for spoil from this site. Assuming 2,000 tonnes of spoil per hectare, this is equivalent to a P adsorption capacity of 3 t P/ha. The chicken manure used in this study contained a high level of organic P which was apparently made available for plant uptake, and which was held in the spoil in an extractable form (table 2). The extractable P levels were much higher in the chicken manure- and sewage sludge-treated spoil in 1984. This may be due to mineralization of P from the manures. It may also suggest that phosphorus which had been taken up into the vegetation was returned to the spoil in the autumn, and remained in the spoil in an extractable form (Pulford et al. 1984).

The amounts of K extracted from the spoils were more variable from year to year. Although fairly low when compared to acetic acid-extractable K in a soil, these levels probably represent an adequate supply for the plants. Potassium is usually found in reasonably high amounts in coal spoil as it is a constituent of the shale and is released during weathering. Pulford (1976) found a mean for acetic acid-extractable K of 152 mg K/kg, and Lister (1987) measured a mean of 136 mg K/kg exchangeable K (both of these studies being on spoil from Scotland). The low levels of K in the unlimed sample are attributed to acid leaching

Table 1. Vegetation yield and N, P. K recovered in the grass for treated plots, expressed as a percentage of the control plots (no organic amendment) plots for each year.

	1980	1982	1983	1984	1986
Vegation yield					
Chicken manure	722	499	310	226	85
Sewage sludge	226	288	250	227	116
Soil conditioner	34	88	106	157	150
Peat	62	105	83	112	99
Nitrogen recovered					
Chicken manure	-	308	278	161	101
Sewage sludge	-	223	209	173	103
Soil conditioner	-	93	96	133	113
Peat	-	90	84	102	109
Phosphorus recovered					
Chicken manure	-	524	411	272	130
Sewage sludge	-	299	289	245	144
Soil conditioner	-	110	78	136	130
Peat	-	110	100	109	115
Potassium recovered					
Chicken manure	-	-	357	165	102
Sewage sludge	-	-	284	185	98
Soil conditioner	-	-	106	133	108
Peat	-	-	100	108	95

Table 2. Acetic-extractable P and K in Baads spoil, with and without treatments.

	mg P/kg		mg K/kg	
	1983	1984	1983	1984
Chicken manure	17.0	37.9	54.8	107
Sewage sludge	1.5	4.2	41.5	71.4
Soil conditioner	1.0	1.1	54.0	83.1
Peat	1.1	1.0	56.0	73.6
No organic amendment	3.3	1.0	42.4	59.1
No lime, no organic amendment	0.3	0.4	1.0	3.6

Table 3. Carbon and nitrogen mineralised over 10 weeks

Treatment		Amount of element mineralized (mg/kg) mean and (standard deviation)					
		1982		1983		1984	
Chicken manure	C	782	(161)	1907	(312)	1940	(647)
	N	-		33.3	(13.8)	34.1	(15.7)
	C:N	-		57		57	
Sewage sludge	C	696	(140)	1501	(205)	1784	(342)
	N	-		19.4	(5.9)	24.1	(7.0)
	C:N	-		77		74	
Soil conditioner	C	700	(189)	1586	(137)	1431	(310)
	N	-		17.0	(7.5)	29.5	(13.6)
	C:N			93		49	
Peat	C	730	(209)	1650	(51)	1873	(927)
	N	-		18.0	(6.4)	23.0	(11.9)
	C:N	-		92		82	
No. org. amendment	C	451	(238)	1128	(498)	1508	(226)
	N	-		22.8	(8.3)	31.6	(14.5)
	C:N			49		48	
No lime, no org. amendment	C	119	(40)	143	(27)	160	(51)
	N	-		4.0	(3.4)	1.5	(2.8)
	C:N	-		36		133	

(Pulford and Duncan 1978).

Whereas the status of P and K in the spoil can be assessed using extraction data, that of nitrogen is more difficult to interpret. Total N levels mean very little as there is a significant amount of nitrogen in the organic component of the shale. Although this "fossil nitrogen" may be released on weathering, the rate at which this occurs is so slow, except under extremely acid conditions, that the amount of N made available for plant uptake is insignificant. The levels of extractable inorganic NH_4+ and NO_3- reflect the nitrogen status of a very small fraction of total N at a particular stage of the nitrogen cycle. For these reasons it was felt to be preferable to measure the amount and rate of N mineralized from spoil during incubation over a fixed time period. As this is a microbiologically mediated process, the amount of carbon turned over during the same period was also measured.

Table 3 shows the amounts of C and N mineralized over a 10- week period of incubation. In all cases, large amounts of carbon were turned over in comparison to nitrogen, which is reflected by the high values of the C:N ratios. There was considerable variation in the levels of C and N mineralized between samples. Within any one year, there was no significant difference between treatments for the limed plots, but significantly less C and N were mineralized in the unlimed control plots. Comparison of these results with those of previous studies is difficult due to the variety of methods used. For example, Reeder and Berg (1977), Palmer and Chadwick (1985) and Fyles and McGill (1987) all used air-dried spoil, whereas in this study fresh spoil was used. Similarly there are a number of incubation systems which have been used. Despite these variations, however, it has usually been the case that far more carbon than nitrogen is released in this type of incubation. Even though the levels of N measured are low, they may represent the most important pool of N available to plants. Palmer and Chadwick (1985) found that mineralizable nitrogen was the fraction most highly correlated with herbage nitrogen.

Cumulative plots of carbon and nitrogen mineralized showed that after an initial flush, due to disturbance on sampling and handling the spoil, the release of carbon dioxide was linear from weeks 4-10, allowing an estimate of the rate of release at equilibrium to be made. There was initially immobilization of nitrogen, but the rate of release was linear for weeks 1-10, allowing an estimation of the rate of N release. These zero order rate constants for C and N release are shown in table 4. As in the study of Fyles and McGill (1987), nitrogen mineralization did not follow first order kinetics, and so values of potentially mineralizable nitrogen (N_o) could not be measured (Stanford and Smith 1972), Reeder and Berg 1977). C:N ratios calculated on the basis of rates of mineralization were lower than for those calculated from total carbon and nitrogen mineralized, due to the initial immobilization of nitrogen.

The evidence from the levels of extractable P and K, and the rates of turnover of C and N suggest that nitrogen and phosphorus are very deficient in these spoils. A fertilizer response trial showed vegetation yield increased significantly ($p < 0.05$) only when 100 kg N/ha was applied (table 5). No effect on vegetation yield was measured by additions of P or K alone, or by 50 kg N/ha. Similarly, when a combination of N, P, and K were added, there was a significant response only at the high rate of N. A yield response to added N has commonly been recorded (Bradshaw 1983); the effect of P is less clear. Fitter and Bradshaw (1974) and Doubleday and Jones (1977) both showed an increase in vegetation yield with added P. Pulford and Duncan (1978) measured only a slight decrease in yield in two spoils, and no effect in a third spoil, when no phosphate was added in a pot trial. Addition of 60 kg P/ha, alone or with N and K, increased the phosphorus content of the vegetation; therefore some of this added P was available and taken up. Moreover, where a high level of N with no added P led to a yield increase, the phosphorus content of the grass did not decline, implying that additional P was taken up and so was not limiting to growth.

A detailed study was carried out on various transformations in the nitrogen cycle on 90 samples of coal mine waste from sites throughout central Scotland, representing a wide range of properties (table 6). Carbon dioxide evolution and nitrogen mineralization rates showed that a high level of carbon, but little nitrogen, was turned over. Nitrification was measurable only on about half of the sites studied, and was, as expected, highly pH dependent, being inhibited below approximately pH 5.5. However, even on sites above this pH, nitrification was not invariably measured, suggesting that the introduction of nitrifying bacteria into the spoil was also an important factor. Some N was lost due to ammonium fixation by the clay minerals of the shale. In the spoils which showed the highest degree of ammonium fixation, up to 23% of the 100 mg/kg NH_4-N added was lost in this way. Low levels of extractable inorganic N were found.

Table 4. Zero order rate constants for C and N turnover during incubation at 22°C.

Treatment	Zero order rate constants		
	mg CO_2-C released per kg spoil/week	mg N released per kg spoil/week	C:N
Chicken manure	146.4	3.80	39
Sewage sludge	127.5	2.72	47
Soil conditioner	101.4	3.29	31
Peat	143.6	2.48	58
No organic amendment	102.0	3.46	29
No lime, no org. amendment	16.5	0.68	24

Table 5. Fertilizer response plots - herbage yield and NPK content

N (kg/ha)	P	K	Herbage yield* (t/ha)	Herbage content N	P	K
0	0	0	1.7^{a}	1.16	0.16	1.46
50	0	0	1.6^{a}	1.17	0.18	1.04
100	0	0	3.3^{b}	1.37	0.19	1.16
0	30	0	1.2^{a}	1.53	0.22	0.85
0	60	0	1.2^{a}	1.44	0.32	1.09
0	0	30	1.8^{a}	1.11	0.20	0.73
0	0	60	1.3^{a}	1.34	0.20	0.76
50	30	30	1.3^{a}	1.29	0.24	0.85
100	60	60	2.6^{b}	1.50	0.30	1.17

*Values with the same letter following are not significantly different at the 5% level using a Fisher LSD test.

Table 6. Survey of nitrogen status of 90 experimental sites on coal spoils.

	Minimum	Maximum	Mean
pH (in water)	3.0	8.8	5.9
CO_2 Evolution (mg C/kg/wk)	19.5	181.4	62.6
N Mineralization (mg N/kg/wk)	0.0	3.2	0.8
Nitrification (mg N/kg/day)	0.0	10.2	3.6
NH_4+ Fixation (mg/kg)	0.0	22.9	6.0
Inorganic N (mg/kg)	0.1	31.4	3.4

* Only 46 of the 90 sites investigated showed detectable nitrification. The mean is calculated on the basis of those 46 sites only.

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DIRECT REVEGETATION OF ANTHRACITE REFUSE USING COAL FLY ASH AS A MAJOR SOIL AMENDMENT[1]

John K. Buck and Robert J. Houston[2]

Abstract.--The Pennsylvania Power and Light Company (PP&L) used fly ash as a major soil amendment to prepare a 10-acre anthracite refuse site for direct (soil-less) revegetation. The site is located at Harwood, near Hazleton, PA. In the laboratory, experimental mixtures of fly ash and anthracite refuse were used to estimate the chemical and physical suitability of various rates of fly ash amendment for establishment of vegetation. Based on laboratory studies, fly ash was applied to the anthracite refuse at a rate of 200 dry tons/acre, and was plowed, in combination with agricultural limestone and fertilizers, into the refuse to a depth of 10 inches. For comparison, a soil-covered "control plot" was established at the site. The site was seeded in September 1984. Fly ash amendment improved the physical and chemical characteristics of the anthracite refuse by increasing the plant available water-holding capacity, shifting the USDA textural class of the refuse from sandy loam to silt loam and improving the pH and fertility of the coal refuse materials. Vegetation response has been vigorous in fly ash-amended coal refuse areas and is comparable to that in the soil-covered control plot. Excellent erosion control and partial release of the revegetation performance bond was achieved in the establishment year. Plant tissue analyses conducted recently indicate normal uptake of nutrients and trace elements from fly ash-amended coal refuse materials, with the exception that molybdenum and selenium uptake was high. Surface water quality improved as a result of the reclamation program.

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INTRODUCTION

At the Harwood site, anthracite refuse materials were directly vegetated without using soil and using Class F fly ash as a major soil amendment. Direct (soil-less) revegetation of the site was considered to avoid the economic cost of obtaining borrow soil from a location off site and to avoid the environmental costs (reduction in borrow site productivity) of removing soil from a borrow site. Direct revegetation concepts and examples at four contrasting sites, including the Harwood site, are described by Buck and Houston, 1987.

Fly ash was considered as a soil amendment to neutralize part of the coal refuse acidity, to provide major and trace nutrients, and, most importantly, to improve soil texture and water retention by addition of fines to the coarse-textured refuse. Addition of the light-colored ash to the dark refuse was also expected to reduce heat absorption and thus reduce water losses.

Site Background

Harwood, located near Hazleton in northeastern Pennsylvania, is an abandoned mine-mouth anthracite coal-fired electric generating station owned by the Pennsylvania Power and Light Company (PP&L). The Harwood reclamation site is just west of the south-bound lane of Interstate 81 at a point 0.6 miles south of the PA-924/I-81 interchange.

The 10-acre reclamation site was once used in a coal cleaning process to store anthracite coal fines. The refuse coal discharged from the coal breaker/processing plant had filled a sedimentation pond with fine anthracite coal particles typical of those discarded in the early 1900's. In 1984 the anthracite fines were excavated, cleaned, and burned at electric generating stations. After reprocessing in 1984, PP&L was required under provisions of a surface mining permit to regrade and revegetate the disturbed area.

The Class F fly ash used in the reclamation program came from PP&L's Montour Electric Generating Station, 40 miles to the west. The bituminous coal from which the fly ash was derived originated from the Greenwich Mines in north-central Pennsylvania. Thus, the utility company used its reclamation site to demonstrate constructive use of its own fly ash as a soil amendment.

METHODS

General Approach

The goal of this project was to demonstrate the beneficial use of fly ash in reclamation of coal-mined land. Fly ash applications had to be: 1) cost effective; 2) practical to apply and mix into the coal refuse; and, 3) not detrimental to plant growth or water quality, or to animals consuming forage grown on ash-amended refuse.

An empirical soil chemistry approach was used to evaluate the chemistry of fly ash-amended coal refuse before any ash was placed in the field. It consisted of:

1) identifying and sampling each major type of coal refuse;

2) making laboratory mixtures of fly ash and coal refuse, then allowing the mixtures to approach equilibrium by wetting and air-drying;

3) analyzing the fly ash, coal refuse materials, experimental ash/refuse mixtures, and (control plot) borrow soil using appropriate soil tests;

4) designing/implementing a soil amendment and seeding plan;

5) monitoring vegetation success and soil and water quality for 5 years;

6) analyzing plant tissue to determine potential impacts to wildlife using the site; and,

7) developing protocols for design of ash utilization projects elsewhere.

Special Design Concerns Associated with Fly Ash Use

Research has shown that soluble salt and soluble boron (B) concentrations associated with fly ash may be toxic to some plants and thus may limit the usefulness of fly ash as a growing medium or soil amendment (Adriano et al. 1980). Where soluble salts and boron are not toxic to plants (phytotoxic), excessive plant uptake and accumulation of certain elements, especially molybdenum (Mo) and selenium (Se), can pose a danger to animals grazing on plants grown in fly ash or fly ash-amended soils (Adriano et al. 1980).

If the fly ash has self-hardening properties, it may cause excessive soil crusting if used as an amendment. Because Type F fly ash (the type used at Harwood) is not typically self-hardening, this was not a concern.

Sampling and Analysis

Sampling

A field survey was done in July 1984 after grading was complete. Based on the results of the field survey and preliminary laboratory analyses, the site was divided into three distinct coal refuse zones and a 0.5-acre control plot, covered with borrow soil to a 10-inch depth, was established to compare revegetation success with and without borrow soil. Composite samples (made from at least 10 subsamples) were collected from the surface 10-inch depth of each coal refuse zone and the borrow soil plot.

Plant tissue samples were collected in June, 1987 from 10 evenly spaced locations in each coal refuse zone and the control plot. Samples were dried at 60°C then ground in a stainless steel mill to pass a 20-mesh sieve prior to analysis. Live plant biomass was determined by shearing the grass/legume sward along 0.1 x 1.0 meter transects at 10 locations in each zone, drying at 80°C, and weighing each subsample.

Physical Analyses

Particle size analyses were done in accordance with ASTM Method D-422. Plant-available water holding capacity was determined using a pressure membrane apparatus and was calculated as the difference in moisture content at -0.33 bar (field capacity) and -15 bar (permanent wilting point) moisture tension (Klute, 1986).

Laboratory Mixtures

Mixtures of Greenwich fly ash and coal refuse were made in the laboratory to estimate the field reaction of 200- and 300-ton/acre applications (dry weight basis) of fly ash to the coal refuse. The 200-ton/acre (2.0 inches deep) application rates correspond to field ash:coal refuse ratios of 1:4, 1:6, and 1:8 when ash is mixed with the refuse to a depth of 7, 10 and 12 inches, respectively. A 300-ton/acre (3.0-inch-deep) ash application rate corresponds to a field ash:refuse ratio of 1:4 when ash is mixed with the refuse to a depth of 10 inches.

Most of the agronomically significant physical and chemical properties of soils (e.g. water holding capacity, compactability, cation and anion exchange capacity) are attributed to the "fine-earth" (<2.0-mm) size fraction of soils. For this reason bulk (field) fly-ash:coal-refuse ratios of 1:4, 1:6, and 1:8 were represented in the laboratory by mixtures of the fine-earth fraction of the fly ash and coal refuse materials. Fine-earth-sized fly ash and coal refuse materials were mixed in ratios which were adjusted for the relatively inert coarse fractions of the coal refuse and fly ash components.

The ratios of fly ash and coal refuse most appropriate for creation of acceptable growing media were determined experimentally by: 1) mixing the components; 2) moistening the mixtures to 50% moisture (dry weight basis) to allow the constituents to approach chemical equilibrium, air-drying the mixtures; and 3) analyzing each mixture using conventional soil chemical assays.

Chemical Analyses

The coal refuse materials, fly ash, partially-equilibrated mixtures, and borrow soil samples were assayed at the Pennsylvania State University Soil and Environmental Chemistry Laboratory for pH (1:1 water:soil) and lime requirement (SMP-buffer) (McLean, 1982), soluble salts (electrical conductivity of a 2:1 water: soil extract) (Rhodes, 1982), Bray-1 P (Olsen and Sommers, 1982), neutral, normal ammonium acetate extractable Ca, Mg, and K (Thomas, 1982), and, using the Baker-method, for plant-available Ca, Mg, K, Mn, Fe, Cu, Zn, Na, Al, Pb, Ni, and Cd (Baker and Amacher 1981). Concentrations of hot water soluble B (Bingham 1982), oxalic acid (Tamms) extractable Mo (Reisnauer 1965), and total Se (Fine 1965) were also determined. Beginning in 1986, saturation extracts were assayed for soluble salts (Rhodes, 1982) and B (Bingham, 1982).

PRE-APPLICATION RESULTS AND DISCUSSION

When soluble salt levels measured by electrical conductivitity exceed 2.0 mmhos/cm, yields of very salt sensitive plants are reduced (Rhodes, 1982). Boron becomes toxic to most agricultural species when hot water soluble B exceeds 20 mg/kg soil (Hodgson and Townsend, 1969) and was adopted as a B phytotoxicity threshold. Soluble salt and B levels of the fly ash were high, but laboratory mixtures indicated that mixing the ash with the coal refuse reduced B and soluble salt concentrations to acceptable levels (Table 1). It is important to note that soluble B in fly ash is not always "diluted" upon mixture with low B materials. We have observed at fly ash disposal sites that soil/ash interactions sometimes increase B solubility to levels above that of either component. This underscores the need for testing of equilibrated or partially-equilibrated experimental mixtures.

Table 1.--Results of pH, soluble salts, boron, phosphorus, molybdenum, and selenium soil analyses, Harwood anthracite refuse site.

Sampling Date	Sample	pH	Bray P-1 Phosphorus (mg/kg)	2:1 Water:Soil Extract Soluble Salts (EC, mmhos/cm)	Saturation Extract Soluble Salts (EC, mmhos/cm)	Hot Water Soluble Boron (mg/kg)	Saturation Extract Boron (mg/L)	Oxalate Extractable Molybdenum (mg/kg)	Total Selenium (mg/kg)
8/18/84	Greenwich Fly Ash	6.0	95	2.60	-	18.2	-	35.4	6.10
8/18/84*	Stockpiled Borrow Soil	4.7	4	0.10	-	-	-	-	-
9/4/84**	Control Plot Soil	7.6	179	2.20	-	1.2	-	<0.5	<5.0
11/1/84	Control Plot Soil	6.3	84	1.90	-	-	-	-	-
7/8/85	Control Plot Soil	5.5	32	0.16	-	1.3	-	-	-
6/27/86	Control Plot Soil	6.0	14	0.10	0.66	1.3	0.15	-	-
6/2/87	Control Plot Soil	5.6	26	0.10	0.50	1.0	<0.05	0.73	0.53
8/18/84*	Zone 1 Refuse	3.9	8	0.40	-	0.8	-	0.4	6.4
Lab Mix#	Zone 1 AACR	5.0	57	1.20	-	4.4	-	-	-
9/4/84**	Zone 1 AACR	7.0	18	0.16	-	5.7	-	7.3	<5.0
11/1/84	Zone 1 AACR	7.1	76	2.20	-	11.2	-	-	-
7/8/85	Zone 1 AACR	7.0	89	1.30	-	6.4	-	-	-
6/27/86	Zone 1 AACR	7.1	89	0.76	2.10	2.6	0.63	-	-
6/2/87	Zone 1 AACR	6.5	89	0.67	2.40	2.2	0.61	8.40	6.67
8/18/84*	Zone 2 Refuse	4.0	6	0.32	-	1.2	-	0.2	3.14
Lab Mix#	Zone 2 AACR	4.9	84	1.08	-	3.7	-	-	-
9/4/84**	Zone 2 AACR	7.1	73	2.20	-	9.4	-	5.3	<5.0
11/1/84	Zone 2 AACR	6.9	89	2.00	-	6.8	-	-	-
7/8/85	Zone 2 AACR	7.1	78	1.80	-	7.2	-	-	-
6/27/86	Zone 2 AACR	6.7	89	1.62	2.80	3.7	1.33	-	-
6/2/87	Zone 2 AACR	6.9	114	1.31	2.50	2.5	0.86	13.1	4.64
8/18/84*	Zone 3 Refuse	3.9	3	0.14	-	0.6	-	0.2	9.2
Lab Mix#	Zone 3 AACR	6.1	82	1.70	-	6.2	-	-	-
9/4/84**	Zone 3 AACR	6.7	82	2.00	-	5.5	-	7.0	<5.0
11/1/84	Zone 3 AACR	6.3	54	0.40	-	8.6	-	-	-
7/8/85	Zone 3 AACR	7.2	95	1.20	-	4.0	-	-	-
6/27/86	Zone 3 AACR	7.4	105	0.32	1.25	2.9	0.49	-	-
6/2/87	Zone 3 AACR	7.5	132	0.45	1.70	2.5	0.52	8.78	6.65
6/21/85	Zone 1 0-10"	6.8	87	0.80	-	1.8	-	-	-
6/21/85	Zone 1 10-20"	4.0	15	0.50	-	0.8	-	-	-
Soil Criteria for Concern Regarding Plant Toxicity in Sensitive Species:				>2.0	>2.0-4.0	>20.0	>1.0		

*Before Amendment with fly ash (Zones 1-3 only), limestone and fertilizers. AACR = Fly Ash Amended Coal Refuse
**Day of seeding, after amendment with fly ash (none in control plot), limestone, and fertilizers.
#The 1:6 ash:refuse mixtures made in laboratory are reported here. Mixtures of ash and refuse were also made in 1:4 and 1:8 ratios. These experimental mixtures did not contain added limestone or fertilizers.

The available nutrient and trace element status (by Baker test) of the experimental mixtures was better than that of the components. Mixing fly ash into the coal refuse increased the pH, decreased potentially phytotoxic aluminum solubility, and increased the concentrations of major nutrients and essential trace elements, especially phosphorus (Table 1). The inherent fertility of the fly ash-amended refuse materials was higher than that of the control plot borrow soil (with the probable exception of nitrogen, which was not assayed for). Availability of potentially toxic heavy metals (Pb, Ni, Cd) tested low-to-normal for the experimental mixtures assayed by the Baker method.

Molybdenum and selenium assays were used to compare trace element concentrations with soils (Table 1). Although these elements are not typically toxic to plants, Mo and Se can accumulate in forage and potentially become toxic to livestock intensively grazed on high (5-20 mg/kg) Mo and/or high (4-5 mg/kg) Se feed (Adriano, et al. 1980). Because Mo and Se tested higher for the unweathered experimental mixtures than soils, and reliable soil Mo and Se availability indices are not available (Adriano, 1986), it was recommended that fly ash-amended coal refuse areas at Harwood not be used for intensive (confined) livestock grazing unless future testing of the soil and forages indicated this was a safe practice. Follow-up soil and forage analyses are discussed later.

Revegetation Plan

Fly Ash, Limestone, and Fertilizer Requirements

Although our analyses of experimental mixtures indicated that Greenwich fly ash applications of up to 300 dry tons/acre could be used as a soil amendment at the Harwood site, an application rate of 200 dry tons fly ash/acre, incorporated to a 10-inch depth was chosen (This application rate is represented by the 1:6 ash:coal refuse laboratory mixtures).

Based on soil tests on the experimental mixtures, fertilizer and limestone requirements of the ash-amended refuse materials were less than required for the soil-covered control plot. Commercial N-P-K fertilizers and high-magnesium limestone were used to balance the nutrient and lime requirements of the fly ash-amended refuse and the control plot soil. Soil amendments used are given in Table 2.

Seeding Mixture

A fall seed mixture was designed to provide quick cover and establish permanent species tolerant of wet or dry conditions and low pH. Although the pH of the coal refuse could be increased to pH 7, acid-tolerant species were chosen because: 1) they could survive a decline in soil pH; 2) some areas might not be sufficiently neutralized by lime and fly ash; and, 3) acid-tolerant species could also exploit water and nutrients in the unamended, acidic subsoil. To quickly provide temporary cover and erosion control, winter rye (Secales cereale) and annual ryegrass (Lolium multiflorum) were used. Redtop (Agrostis alba), reed canarygrass (Phlaris arundinacea), deertongue grass (Panicum clandestinum), and birdsfoot trefoil (Lotus corniculatus) were the perennial species chosen.

Construction Methods

A soil-covered control plot was established at the center of the site. Soil amendments (Table 2) were incorporated into the top 10 inches of the fly ash/refuse mixtures with a chisel plow. The site was hydraulically seeded. Straw mulch was spread at a rate of 3 tons/acre and tacked in place using cellulose-fiber mulch hydraulically applied at the rate of 800 pounds/acre. All of this work was completed within 2 1/2 days in early September 1984.

RESULTS: POST-RECLAMATION MONITORING

Soil chemistry, soil physical properties, surface water quality, soil pore (lysimeter) water quality, and vegetation success have been monitored since the site was reclaimed in September of 1984. Vegetation yield and elemental composition was monitored in 1987 to determine nutrient and trace/potentially toxic element content. Monitoring will continue on at least an annual basis through 1988.

Vegetation Monitoring

Erosion control was excellent in all areas of the site. Erosion control was enhanced by chisel-plowing along contours which left 4- to 6-inch furrows to catch rainfall and seed. Initial fall growth was confined mainly to winter rye, which grew uniformly throughout fly ash-amended coal refuse areas and the soil-covered control plot. Redtop also took hold that fall, but was too small to contribute much to erosion control. Where fly ash or soil was not used, growth was weak. First-year vegetation was stronger and more uniform within the soil-covered control plot.

In the summer following seeding, winter rye, reed canarygrass and redtop matured and set seed. In descending order of predominance, reed canarygrass, birdsfoot trefoil, annual ryegrass, and

Table 2.--Soil Amendments used at the Harwood Anthracite Refuse Site (incorporated to a 10-inch depth).

	Soil Amendments		
Test Plots	Fly Ash (dry tons/acre)	Fertilizer* (lb N-P_2O_5-K_2O/acre)	Limestone** (tons $CaCO_3$ equiv./acre)
Zone 1 refuse/ash	200	200-50-200	4.5
Zone 2 refuse/ash	200	200-50-200	6.5
Zone 3 refuse/ash	200	200-50-200	5.0
Soil-covered control	0	200-200-200	7.0

*80 of 200 lb n/acre were applied in a slow-release form.
**Limestone containing at least 9 percent MgO equivalent was used to supply at least 240 lb/Ac Mg.

deertongue grass became established as secondary species the first summer (1985). Vegetal cover exceeded 70 percent in all areas by visual estimate.

In the second summer after seeding, winter rye and annual ryegrass had vanished from the sward while redtop, reed canarygrass, and birdsfoot trefoil (in descending order) took predominance. Third-year vegetation shifted toward a reed canarygrass/birdsfoot trefoil-dominated sward. Vegetal cover on fly ash-amended coal refuse areas was strong and indistinguishable from that on the soil-covered control plot.

Examinations of peripheral areas suggested that even where coarse-textured refuse materials are supplied with adequate water (as in unamended areas near swales), refuse amended with fly ash support a more uniform and diverse stand of vegetation. This may be due, in part, to improved soil water retention and fertility, as well as to textural changes which result in better seed/soil contact.

Physical Changes in Growing Media from Fly Ash Amendment

As expected, fly ash amendment increased the "fine earth" (<2.0 mm) fraction of the anthracite refuse, with a notable increase in silt content (Table 3). Fly ash amendment shifted the coal refuse textural classes of the refuse materials from sandy loam to silt loam in all zones of the site. As expected, fly ash-amended coal refuse materials have increased plant available water holding capacity (Table 3). The fly ash-amended coal refuse tested had the highest plant available water holding capacity--greater than the fly ash alone, the unamended refuse, and the borrow soil, in descending order.

Chemical Monitoring of Ash-Amended Coal Refuse Materials and Soil

The surface 10 inches ("plow zone") of the soil-covered control plot and each of the three fly ash-amended coal refuse areas were sampled on the day of seeding and during each of our annual monitoring visits.

All samples were analyzed for the same chemical parameters described earlier. Results of pH, P, soluble salts (conductivity), B, Mo, and Se tests on unamended refuse, experimental mixtures, control plot soils, and actual field mixtures are summarized in Table 1.

The experimental mixtures adequately predicted the chemistry of the ash/coal refuse mixtures produced in the field. Over time, mixtures of ash and coal refuse have remained within an optimal pH range. From the beginning of the program, hot water soluble B concentrations remained below the guideline for phytotoxicity (20.0 mg/kg) and have since weathered to levels more typical of Pennsylvania soils. Levels of soluble salts were acceptable, with a decreasing trend over time. Contrary to expectation, the pH of the soil-covered control plot dropped considerably after seeding.

Analyses of soil saturation extracts were begun in 1986 for B phytotoxicity evaluation and estimation of the potential for soluble salt phytotoxicity. The saturation extracts more closely simulate the ionic composition of the soil solution from which plants absorb nutrients (and toxic substances). Recent literature (Keren and Bingham 1975) indicates that the saturation extract method is better for evaluation of B phytotoxicity potential than the hot water method. (The hot water soluble B assay is still best for diagnosing B deficiency.) Very boron-sensitive crops can tolerate soils with saturation extract concentrations up to 1.0 mg B/L. Tolerant species (e.g., alfalfa) can tolerate up to 15 mg B/L (Sprague 1972). By these methods and

Table 3.--Results of soil texture and plant available water holding capacity assays, Harwood Anthracite Refuse Site.

Sample	% Fine Earth** (<2.0 mm)	Particle Size Distribution of Fine Earth Fraction* % Sand	% Silt	% Clay	USDA Textural Class	Plant-Available Water Holding Capacity** (%, dry wt.)
Greenwich Fly Ash	100.0	19.0	71.0	10.0	silt loam	10.45
Control Plot Borrow Soil	70.9	14.0	72.0	14.0	silt loam	6.12
Zone 1 Coal Refuse	50.2	69.0	23.0	8.0	sandy loam	9.53
Zone 1 Fly Ash Amended Coal Refuse	69.7	22.0	68.0	10.0	silt loam	---
Zone 2 Coal Refuse	64.0	59.0	31.0	10.0	sandy loam	---
Zone 2 Fly Ash Coal Amended Refuse	68.4	15.0	73.0	12.0	silt loam	17.59
Zone 3 Coal Refuse Refuse	26.0	72.0	21.0	7.0	sandy loam	---
Zone 3 Fly Ash Amended Coal Refuse	49.2	19.0	71.0	10.0	silt loam	---

*Sieve and hydrometer analyses were conducted in accordance with ASTM Method D-422.
**Determined as the difference in moisture content at field capacity (-1/3 bar moisture tension) and the permanent wilting point (-15 bar moisture tension).

criteria, the samples collected in 1986 and 1987 are not phytotoxic, although B and soluble salt concentrations are higher in the fly ash-amended coal refuse zones than in borrow soil.

Soil assays for Mo and Se were high and suggested that the fly ash-amended coal refuse could potentially produce forage containing excessive concentrations of those elements (if that forage is the sole food source). Soil in the control plot contained very little Mo and Se. Plant analyses done in June 1987 support concerns arising from soil analysis (discussed below).

The nutrient and trace element availability assays by the Baker method (not reported) indicated that nutrient and trace element availability have remained nearly ideal for the ash-amended coal refuse zones and for the soil-covered control plot. Availability of non-essential/potentially toxic elements [sodium (Na), aluminum (Al), lead (Pb), nickel (Ni), and cadmium (Cd)] consistently tested low-to-normal by the Baker method for all fly ash-amended coal refuse and soil samples analyzed.

Water Quality Monitoring

Pennsylvania Power and Light's Environmental Management Division has conducted a soil pore water and surface water quality monitoring program at the site Results are summarized in detail elsewhere (Buck and Houston 1987; Buck 1987).

Except for pH increases following a companion reclamation project adjacent to the offsite pond, reclamation activities apparently caused no significant changes in the water quality of the onsite spring, the offsite pond, or the water in the creek at the property line (downstream of the swale drainage). Runoff water quality in the drainage swale at the center of the site improved as a result of reclamation activities (pH increased and Al, Cu, Mn, Zn, As and Se decreased).

Biomass Yield Comparison

Live plant biomass yields were highly variable within each coal refuse zone and within the control plot when sampled in June 1987. This variability is explained by the sampling method--short (1.0 m) transects through birdsfoot trefoil yielded much more than areas covered with grasses. Average dry weight yields were higher in the coal refuse plots (range: 393.7 to 1134.3 lb/Ac) than in the soil-covered control plot (278.1 lb/Ac), but are of dubious comparative value because of excessive sample variance (C.V. range = 90.7 to 116.3 percent).

Plant Tissue Analyses

Birdsfoot trefoil and reed canarygrass composite samples were collected in June 1987. At the time of sampling, less than 5 percent of the birdsfoot trefoil had gone to flower and less than 10 percent of the reed canarygrass was at the "boot" stage or older. Only established plants (over 1 year old) were sampled. Dry spring weather and moderate soluble salt concentrations may have put the plants under some stress.

Results of analyses plus expected values (Penn State) and chronic animal feed toxicity guidelines (National Research Council 1980) are presented in Tables 4A and 4B. As expected, concentrations of Mo, Se, B, and As were elevated where plants were grown using fly ash as a soil amendment. Arsenic and B concentrations in plant samples were all low and of no toxicological concern. Molybdenum in birdsfoot trefoil and Se in both species exceeded National Research Council (NRC) guidelines for chronic toxicity in animals (NRC, 1980). Molybdenum data suggest that animals should not be exclusively grazed on the fly ash-amended portions of the Harwood site. Molybdenum toxicity to wildlife is unlikely because animals using the site (particularly deer) have large home ranges and do not exclusively feed on Mo-rich birdsfoot trefoil. If the site were to be used by confined ruminant animals (e.g. cattle, sheep), Mo toxicity could be a problem especially if dietary intake of Cu were low. Selenium concentrations exceeded recommended forage concentrations, but are not extremely high. Unconfined wildlife should not be affected adversely because adjacent lands, like most of the northeast, produce low-Se forage. Thus livestock should not be exclusively grazed on or fed from Harwood fly ash-amended coal refuse materials unless testing of forage for Se, Mo, and other elements indicates that the forage is safe. There are no plans to convert any part of the Harwood site to agricultural use.

Relationship Between Plant Tissue Analyses and Soil Analyses

Plant analyses done to date affirm the validity of the soil tests used to predict the potential for plant toxicity or food web contamination. Based on experience to date, it is believed that the saturation extract assay for soluble salts (Rhodes 1982) and B (Bingham 1982), Bray-1 P (Olsen and Sommers 1982), and the Baker method of soil testing (Baker and Amacher 1981) are appropriate for pre- and post-reclamation analyses of fly ash-amended coal refuse materials. Soil Se and Mo soil assays are not adequate predictors of Se and Mo uptake, especially for unconventional soils (Adriano 1986). More predictive Se and Mo soil assays need to be developed. In the interim, forage nutrient content, including Se and Mo, should be done prior to feeding the forages to livestock.

Cost Comparison

The revegetation of the Harwood site cost $4,053/acre. This figure includes a trucking cost of $4.19/ton for fly ash from the Montour Station, which is approximately 45 miles from the site. Cost estimates for placing 6 inches of soil on the control area at the site and treating as required were $5,272/acre. Cover soil was not available on site, but suitable soil was available on PP&L property approximately 1 mile from the site. For the 10-acre project, PP&L estimated the savings due to using fly ash instead of a 6-inch soil cover to be $12,000.

These cost comparisons are conservative. If soil was not available from the owners' property or if thicker soil cover were used, costs of the conventional soil cover treatment would be much higher. Fly ash trucking costs were higher than for a site more convenient to the fly ash source. Fly ash disposal costs to the utility were also saved, but these costs were not included in the analysis described above.

CONCLUSIONS AND RECOMMENDATIONS

Fly ash was successfully used as a soil amendment to prepare anthracite refuse for direct revegetation. The growth of vegetation on fly ash amended coal refuse was comparable to growth on borrow soil. Impacts to water quality were acceptable. Forage quality was acceptable for use by wildlife with large home ranges. Soil chemistry was stable and at nearly ideal pH and nutrient levels. Reclamation costs were less when fly ash was used in mixture with anthracite refuse instead of cover soil.

It is important to note that not all fly ash is appropriate for use as a minesoil amendment. Unique chemical interactions between fly ash and coal refuse should be taken into account by evaluating experimental fly ash/refuse mixtures as well as the separate components. Pyritic, acid-generating coal refuse and spoils should be carefully evaluated with regard to potential acidity problems. The potential for plant toxicity, degradation of water quality, Table 4A.--Concentrations of major nutrients in composite samples of plant tissue, Harwood anthracite refuse site, June 1987.

Sample I.D.	Sample Description	N	P	K	Ca	Mg	S
		(percent, dry weight basis)					
Z1RC687	Zone 1 Reed Canarygrass	2.46	0.41	2.71	0.34	0.20	0.53
Z2RC687	Zone 2 Reed Canarygrass	2.43	0.43	2.75	0.37	0.21	0.55
Z3RC687	Zone 3 Reed Canarygrass	2.26	0.41	2.64	0.30	0.19	0.43
CP4C687	Control Plot Reed Canarygrass	2.17	0.35	2.62	0.21	0.28	0.36
Expected Range for Grasses (PSU)*		1.57-2.94	0.16-0.30	1.07-2.31	0.29-0.69	0.10-0.22	0.13-0.27
Z1TB687	Zone 1 Birdsfoot Trefoil	3.54	0.33	2.90	1.28	0.26	0.44
Z2BT687	Zone 2 Birdsfoot Trefoil	3.16	0.34	3.26	1.26	0.26	0.43
Z3BT687	Zone 3 Birdsfoot Trefoil	3.24	0.34	2.90	1.15	0.24	0.33
CPBT687	Control Plot Birdsfoot Trefoil	3.71	0.35	2.52	0.84	0.38	0.28
Expected Range for Legumes (PSU)*		2.75-4.16	0.26-0.36	1.94-3.18	0.89-1.43	0.16-0.30	0.19-0.33

*Source: The Pennsylvania State University Merkle Laboratory.

Table 4B.--Plant tissue concentrations of trace/potentially toxic elements in composite samples of plant tissue, Harwood anthracite refuse site, June 1987.

Sample I.D.	Sample Description	Mn	Fe	Cu	Zn	Al	Pb	Ni	Sr	B	Mo	Se	As
		(mg/kg, dry weight basis)											
Z1RC687	Zone 1 Reed Canarygrass	91	50	4	30	27	4	4.45	16.0	9.0	1.50	2.02	0.33
Z2RC687	Zone 2 Reed Canarygrass	96	44	3	28	24	5	2.55	18.0	11.0	2.38	2.20	0.50
Z3RC687	Zone 3 Reed Canarygrass	38	52	3	23	34	3	2.75	14.0	8.0	2.86	2.86	0.48
CP4C687	Control Plot Reed Canarygrass	159	58	5	26	37	3	2.65	6.0	6.0	0.61	<0.05	<0.05
Expected Range for Grasses(PSU)*		19-131	44-310	3-19	15-41	27-186							
Z1TB687	Zone 1 Birdsfoot Trefoil	81	114	11	50	41	8	7.35	60.0	48.0	43.0	3.16	0.48
Z2BT687	Zone 2 Birdsfoot Trefoil	74	85	11	40	41	8	6.35	54.0	49.0	93.0	3.26	0.47
Z3BT687	Zone 3 Birdsfoot Trefoil	38	98	10	29	56	6	5.30	53.0	44.0	43.0	5.54	0.30
CPBT687	Control Plot Birdsfoot Trefoil	55	95	9	29	55	6	4.00	12.0	11.0	1.67	<0.05	<0.05
Expected Range for Legumes (PSU)*		11-75	91-345	5-19	10-46	32-234							
Maximum Feed Concentrations Chronically Tolerated by Domestic Animals (NRC)**		400-2000	500-3000	25-1000	300-1000	200-1000	30	50-1000	2000-30000	150	6.2-1000	2	50-100

*Source: The Pennsylvania State University Merkle Laboratory.
**Source: National Research Council, 1980. Mineral Tolerance of Domestic Animals. Nat. Acad. Sci., Washington, DC. 577 pp.

and food web contamination by fly ash-borne elements must be addressed in any fly ash amendment program.

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USING COMPUTERIZED EXPERT SYSTEMS, UNIQUE SOIL TESTING METHODS, AND MONITORING DATA IN LAND MANAGEMENT DECISIONS

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Abstract.--Expert system development software adds new dimensions to computerized interpretation of chemical monitoring data for soil, water, and air. What has come to be known as the Baker Soil Test is an example of an expert system used for land management decisions. The new computer software can make this and other monitoring data even more beneficial to one making land management decisions because more explanation and/or guidance may be passed from the "expert" to the decision maker. Computerized expert systems may be model driven, data driven, and/or expert driven. Reliable systems for land management decisions require a combination of all three approaches and often involve more than one technology. The Baker Soil Test involves a model derived from aqueous solution thermodynamics. The approach places emphasis on the soil solution as a biologically active, dynamic phase with extensive properties attributed to soil solids handled as a "black box". The method was first applied in 1970 to well-characterized agricultural soils with additional correlation data from other soil test methods. The Baker Soil Test has since been used to evaluate "non-soils", including fly ash, coal refuse, and steelmaking slag as well as contaminated soils for their chemical suitability as growing media, and, if vegetated, for potential soil/food-web interactions. The computerized system is consistent, but may not be comprehensive, accessible, or perhaps even logical to some decision makers. Monitoring data and recommendations for land management decisions must be obtained in a consistent and reliable manner and re-evaluated such that decision-making software in expert systems is improved over time. This presentation will review case studies where the Baker Soil Test monitoring data have been used for decision support. The goal of this presentation is to have scientists, consultants, governmental agency regulators, and those making decisions and paying for land management operations become more aware of the need for interaction in the development of alternatives in land management.

INTRODUCTION

Use of a computerized decision-making process to evaluate potential land use requires much integration of knowledge, theory, and data developed over time. Monitoring data must be backed by theoretically sound concepts or approaches; otherwise, the results obtained at one site are not likely to be of value at another location. One objective of this paper is to relate the theory and practice in soil testing which lead to the development of the Baker Soil Test, and the applications of this method for use in decision-making for management and chemical monitoring of disturbed spoils, spoils, coal refuse, coal fly ash and other potential plant growth media.

A second objective is to present the hypothesis that computerized systems can be used by decision makers to obtain the information needed to relate monitoring data and existing technology to site-specific requirements. Experience has shown that specific recommendations made from monitoring data alone are not always sufficient.

EVOLUTION OF THE BAKER SOIL TEST

The Baker Soil Test was developed as a means of evaluating onsite materials for their potential to become growing media, especially where soil cover is unavailable or impractical to obtain. In the 17th century, the Van Helmont experiment demonstrated that soils themselves do not serve as nourishment for plants but simply provide plants with a physical medium of support and with available water containing essential nutrient ions. In addition to water and nutrients from soil, oxygen, carbon dioxide, and sunlight are required for plant growth.

The Van Helmont (1577-1644) experiment was a classical example to support Francis Bacon, who believed that water formed the "principal nourishment" of plants (E.W. Russell 1973). Van Helmont grew a 5-lb willow shoot in 200 lb of dried soil to which he added rain water for exactly 5 years. The resulting tree weighed 169 lb, 3 oz and the soil still weighed 200 lb minus 2 oz. Van Helmont concluded "therefore the 164 pounds of wood, bark, and root arose from the water alone". Later it was postulated that the 2 oz of lost material represented the salts which are essential for plant growth.

Soil fertility experiments today continue to strive to establish optimum levels of salts of the essential chemical elements to add as fertilizers to soil for maximum economical production of specific crops. It is known that carbon (C), hydrogen (H), and oxygen (O), from O_2 and CO_2 in the air plus water, are the most abundant components of plants followed in their general order by nitrogen (N), potassium (K), calcium (Ca), magnesium (Mg), phosphorus (P), sulfur (S), iron (Fe), manganese (Mn), boron (B), zinc (Zn), copper (Cu), molybdenum (Mo), and chlorine (Cl). In addition, animals require macro amounts of sodium (Na) and micro amounts of cobalt (Co), selenium (Se), and probably also chromium (Cr) and nickel (Ni). Producers of field crops know from experience that for every part of N consumed by vegetation, the air, water, and sunlight together supply 40 to 80 parts of dry matter. This synthesis requires optimization of the other essential elements. Over time, the physiology of plants and their mineral nutrition have become very well understood, yet the humus factor in soil management remains to be quantified.

Soil Factors

Management of soil resources requires an integration of all of this technology. It may appear as an oversimplification, but an approach to integration stems from the concept that plants grow in water (the soil solution) which is the continuous phase in the soil-water-air system. Oxygen (O_2) enters the plant root system and carbon dioxide (CO_2) escapes from the respiring root system via diffusion across the water film separating plant roots and soil particles from the large air-filled pores in soils. Soil air is in dynamic equilibrium with the atmosphere through diffusion. Ions essential and nonessential for plant growth are in a dynamic equilibrium with the soil solid phase and the ion absorption sites of plant roots via soil water. Water in soil is exposed to the atmosphere at the soil surface (evaporation) and at the surface of plant leaves (transpiration). Water exists in soil-plant systems as thinly stretched films. The free energy or vapor pressure of soil water must remain between 99 and 100 percent of that of unbound, pure water or plants wilt.

Theory of the Baker of Soil Test

The Baker Soil Test was developed from the hypothesis that plant growth rates are a function of the free energy or chemical potential of ions in the soil solution at the absorption sites on the plant root surface. As ions are absorbed at the root surface, they are replenished by the solid phase via dissolution, desorption, decay in the case of organic matter, or from application of soil amendments. In addition to pH of the soil solution, one must manage soils for pH_2O, pK, pCa, pMg, pH_2PO_4, etc. for every ion and compound essential or beneficial for plant growth and affecting the food web.

In the development of the Baker Soil Test, it was first shown that the activity of an ion (metal or non-metal) and not simply the concentration determines bioavailability of that ion (Baker and Low 1970). From this concept, published data were used to establish boundaries for the appropriate equations relating intensive and relative intensive properties for ions in soil solutions. Standard values for ranges were established for pH, pK, pCa, pMg, pH-1/2p(Ca+Mg), etc. (Baker 1971). Subsequently, the concept was extended to include trace metals (Baker 1973). At this time, the Baker test includes values for the labile quantity and intensity of Ca, Mg, K, Mn, Fe, Cu, Zn, Na, Al, Pb, Ni, and Cd (Baker and Amacher 1981). Assays for plant-available Mo are now under consideration for incorporation into the Baker testing method. Conceptually then, the soil solid phase may be composed of any material which maintains or can be treated to maintain pH_2O, pO_2, pH, pK, pCa, pMg, pH_2PO_4, $pHPO_4$, pNO_3, pNH_4, pZn, pCu, etc., for essential and nonessential elements. In addition to existing standard ranges for each element to predict plant growth and composition, computerized systems could provide more information regarding theory and application.

Use of Non-ideal Growing Media

Economical reclamation and management of disturbed land, especially land disturbed by mining, necessitates the use of non-ideal growing media. Where soil cover is unavailable or impractical to obtain, reclamation practitioners need systems for evaluating the materials available onsite for their potential to become growing media (via amendment). In addition to the potential growing media's physical properties, the chemistry of growing media must be considered:

1) for the present (soil solution nutrient/contaminant ion intensity);

2) in the near future (1-2 growing season soil nutrient/contaminant quantity factors); and

3) in the long term (e.g. potential acidity and associated toxicities from pyrite oxidation).

Examples of these chemical factors, respectively, include:

1) pH, and activity of Fe, Mn, Al, and other nutrients and potentially toxic elements in solution;

2) immediate acidity, labile nutrient/toxic element pool; and,

3) long-term acid production via pyrite oxidation.

EXPERT SYSTEMS APPLIED TO REVEGETATION

The computerized system must establish an If, Then, Else decision-making flow path. For the case of identifying the potential of a waste material to serve in lieu of soil as a growing medium, the investigator determines: 1) if the materials on site are growing media; 2) if not, can they then be amended to become growing media; and 3) if that is not feasible what else can be done with the site (e.g., cover with better material)?

Limiting Factors and Sampling

In determining if the materials on-site are growing media, great cost and time savings can be achieved by first identifying the factor(s) most limiting the development of vegetation on the particular site or portion of the site. This requires some understanding of the history of the site, a field view of current site conditions, and a sampling and analysis program which takes site spatial variability of potential growing media into account. For example, direct revegetation of a coal waste or a heavy metal contaminated site with use of soil or fly-ash or combinations requires that the "worst" materials on site be identified and treated, (not simply the "average" materials represented by composite samples).

Unlike natural soils, sampling of heterogeneous disturbed sites may require that many separate subsamples be analyzed for some or all parameters before composite samples can reasonably be made. Because such a multiple analysis program can be costly, assays for critical parameters which can be done at low cost (e.g., pH and immediate acidity) should be done first. This will help establish the variability of site materials prior to compositing of samples or selecting particular samples for assays of the most expensive of the critical parameters (e.g., potential acidity as pyrite).

Where limiting factors are identified and the range of material characteristics is established, the investigator must then consider whether the worst materials can be selectively treated (e.g., limed) or removed (e.g., excavated and buried), or if a nonselective site-wide treatment aimed at amending the worst materials can be successfully applied yet not compromise the physical and chemical properties of other materials. The more demanding amendment schemes being considered should be experimentally simulated in the laboratory (e.g. liming and wetting/redrying cycles, batch test, etc.) for a wide range of sample types. Then amended samples can be reevaluated for critical parameters as well as parameters of secondary importance.

If the material is a potential growing medium, at least two technical considerations remain: 1) what limitations exist to the final use of the site, specifically, what sort of soil-water plant-herbivore relationships are possible; and, 2) how will the physical and chemical properties of the growing media change over time? The first question is most important for agricultural and, to a lesser extent, wildlife uses, especially for species with broad home ranges--will vegetation produced on alternative growing media be wholesome food for animals? The second question concerns changes in chemistry which may occur with weathering over time. In most humid environments, rainfall and freeze/thaw weathering reactions usually improve the chemical and physical properties of alternative growing media--soluble salts and potentially phytotoxic elements leach out of the root zone. However, the chemistry of pyritic materials may degrade a site over time.

Pyritic Materials--A Long Term Concern

In the case of many mining spoils and coal processing refuse materials, intense acidity generated by pyrite oxidation may radically degrade the amended materials over time and result in the elimination of a vegetative cover. Acidity produced by pyrite oxidation can degrade the soil solution plants depend on, as well as degrade surface and ground water quality. Reclamation of pyritic materials requires that acidity generation be either prevented or neutralized by placement of effective neutralizing agents as it is generated. Although short-term use of anionic surfactants combined with self-sustaining complexing agents produced by vegetation (organic acids) may prevent pyrite oxidation and represent a permanent fix in some cases, the long-term effectiveness of a preventative approach is still under evaluation. Methods of controlling or compensating for pyrite oxidation have been reviewed by Kleinmann and Erickson (1987).

Acid-base accounting methods, while intuitively reasonable, have not been the best predictors of actual pyrite oxidation and acid mine drainage generation (Erickson 1987). The fundamental weakness of the acid-base accounting approach is that it does not consider the relative reactivity of materials and chemical reactions responsible for acid production and neutralization, respectively, by pyrite and carbonate constituents in mineral processing refuse and spoils. Most carbonates present in refuse and spoil materials are in the relatively large (>2 mm) fraction of the particle size distribution and are thus slow to react or are essentially inert. Thus, like Nawrot et. al. (1987), the authors advocate a conservative approach to revegetation of pyritic materials-consider potential acidity from pyrite without regard for native carbonate minerals in the material.

The acidity compensation approach, in which enough limestone is applied to neutralize both immediate and potential (pyrite caused) acidity, is a relatively sure approach as long as 1) the "worst" materials are identified and appropriately treated; 2) treatments are deep enough to allow development of deep, drought-resistant root systems in amended materials; 3) limestone of sufficient fineness is used to assure rapid neutralization of acidity as it is generated; and, 4) acidified water movement from unamended zones does not encroach upon amended zones. Where excess alkalinity is supplied in the form of finely ground agricultural-grade limestone, low carbonate solubility will prevent loss of neutralizing capability by leaching, plus will keep the growing media pH from exceeding approximately pH 8.2. At a soil pH of 8.2, some trace element deficiencies are possible, so the expert system should include laboratory evaluations of such "over-limed" materials to assess the availability of major and trace elements. If such amendment schemes are properly designed, the pH of the materials should be maintained above pH 5.5 and below pH 8.2, even if pyrite oxidation and acid production reaches its potential maximum.

Chemical Evaluation of Alternative Growing Media

All growing media, particularly those which are not natural, uncontaminated soils should be evaluated for their ability to supply essential nutrients and trace/potentially toxic elements to plants. Evaluation of the nutrient/trace element status of an alternative growing medium has historically been made difficult because most conventional soil test interpretive criteria are based on agricultural soils' correlations between fertilizer-dose/yield-response and corresponding soil assay values. Such empirically derived criteria (e.g., the basic cation saturation ratio approach) have little theoretical foundation for application to very dissimilar soils, or to nonsoil alternative growing media such as coal refuse overburden/spoil materials or fly ash. Discussion of the applicability of and limitations on the use of conventional soil tests on drastically disturbed land is presented by Berg, 1978.

The Baker Soil Test is a unique approach which evaluates the nutrient/trace element availability of any growing media on a basis independent of assumptions and empirical relationships obtained from agricultural field plot trials. This approach estimates: 1) the immediate influence of the growing medium on the equilibrium soil solution composition [nutrient and trace/potentially-toxic element intensity (activity)]; and, 2) the size of the labile pool (reserve) in the solid phase of the growing medium capable of buffering solution ion activity.

The Baker test does not measure immediate or potential acidity--this must be addressed using other tests. It is important to note that the Baker test is most useful at or near the pH range that plants can tolerate (pH 5 to 8), so the test should be applied to materials which are (through laboratory amendment where necessary) near this optimal pH range.

The Baker test has been used successfully in many full-scale revegetation projects to check nutrient and trace element balance before and after reclamation. Use of the Baker test to check the chemistry of experimental mixtures of amendments and potential growing media can spare reclamation practitioners the time and expense lost in testing experimental approaches in the field. The approach is also useful in diagnosing causes of differential vegetation success or failure, or differences in plant uptake of particular elements in the field.

Applications of the Expert System Approach Using the Baker Soil Test

From 1974 to 1985, the Baker Soil Test was applied extensively in experiments designed to protect the food chain from excessive accumulations of Cd and other potentially toxic metals applied with sewage sludge and other wastes (Baker et al. 1979, Baker and Chesnin 1975, Hornick et al. 1976, Baker and Amacher 1981, Baker et al. 1984, Williams et al. 1978). In Penn State field plot and greenhouse trials, strong relationships were observed between plant performance, plant major nutrient and trace/toxic element uptake, and Baker Soil Test values of key nutrients and trace/toxic elements. Over time it became increasingly evident that the Baker soil test was an extremely reliable approach for decision support in soil management.

From 1974 to 1982, through the support of Pennsylvania Electric Company, Johnstown, PA, the Baker Soil Test was applied experimentally to nonsoil material (fly ash) and soil-fly ash mixtures. The experiments conducted by Pannebaker (1978) were successful in demonstrating that the Baker soil test provides much of the data needed for the development of a soil and fly ash monitoring program to enable the successful establishment of vegetative cover on fly ash disposal sites using reduced soil cover. Costs of revegetation were minimized by using a minimum soil cover depth and a combination of: 1) soil cover and/or soil-fly ash mixture; (2) chemical fertilizer and lime; 3) selected plant species; and 4) proper management in the establishment phase.

The hypothesis tested by Pannebaker (1978) was that the Baker Soil Test, in conjunction with other soil assays, could be used to predict plant availability of elements which might interfere with successful establishment of vegetation. Many researchers have used comparisons of total elemental analyses of the fly ash with analyses of plant tissue (if plants grew at all) to assess fly ash effects on plant elemental deficiencies or toxicities (Adams et al. 1972; Capp and Adams 1971; Kovacic and Hardy 1972; Capp 1978). As discussed by Baker and Chesnin (1975), total composition results for fly ash or other wastes reflect the relative abundance of elements in the ash compared with the average content in soils or parent materials. However, total abundance is not a reliable predictor of plant availability of chemical elements.

Results of the total elemental analysis of Station 1 fly ash to be stabilized by vegetative cover are reported in table 1. These results showed that the ash is much higher in Al and Fe than normal mineral soils. However, Baker Soil Test results (table 2) indicated that for unweathered fly ash, Al and Fe were normal, but Ca was very high. After 2 years of weathering, the Ca had leached out of the fly ash to nearly normal levels.

The pH of the fly ash (pH 8.6) in a 1:1 ash-water suspension indicated the presence of free CaO and that the fly ash might be used to lime the acid (pH = 4.7) soil. One part ash to 2 parts soil and equal volumes of each were sufficient to give a pH value of 5.5 and 7.0, respectively, after 14 days of equilibration together.

The soluble electrolytes of the fresh ash were high (200 mhos x 10-5/cm)--well above the value of 100 mhos x 10-5/cm tolerated by salt-sensitive field crops grown in Pennsylvania. A 1:2 soil:fly ash mixture reduced the electrical conductivity to desirable levels (less than 100 mhos x 10-5/cm). Thus, the initial experiment indicated that by mixing a 7.5 cm thickness of soil into the upper 15 cm of ash, the soil solution for the resultant 1:2 mixture would have desirable pH and electrical conductivity.

The soil alone was low in K, but the soil-ash mixture substantially increased K availability. Results for a preliminary greenhouse experiment confirmed the validity of the Baker Soil Test results; Pannebaker, 1978.

Field experiments were initiated in the spring of 1976. At that time PaDER (Pennsylvania Department of Environmental Resources) required that closure of a disposal site be accomplished by covering the fly ash with 2 ft of cover soil and establishing a permanent vegetative cover on the soil "unless it is demonstrated....that adequate permanent vegetation can be established with less than 24 inches of cover soil". The goal of the field experiments was to determine the conditions under which much less than twenty-four inches of soil is needed to establish "adequate permanent vegetation" on fly ash disposal areas. The experiments evaluated whether soil-stabilizing vegetative cover could be established on fly ash covered with 0, 6, 12, and 24 inches of soil material and which of these treatments were adequate. The soil material was a mixture of the

Table 1. Elemental compositions (in ppm of dry matter) for soils, and fly ash samples as obtained from complete dissolution of the materials by Na_2CO_3 fusion, or $HClO_3$, HF digestion, and fly ash as found in the literature.

	Soils*		Fly Ash	
Element	Average	Usual Range	Conemaugh Fly Ash Range	Examples from Literature**
P	--	400-3,000	--	300-2,800
S	850	100-1,500	--	400-4,800
Fe	--	14,000-40,000	52,000-132,000	60,900-150,000
Al	--	5,000-32,000	105,000-136,000	76,000-140,000
Mn	850	200-3,000	100-260	200-848
Zn	50	10-300	80-170	90-5,900
Cu	20	2-100	150-180	40-248
B	10	2-100	21-55	48-618
Mo	2	0.2-5	--	20-100
Co	8	1-40	--	65-100
Ba	500	100-3,000	--	750
Cr	200	5-1,000	150-250	900
F	200	--	--	--
Se	0.01	0.1-2.0	--	1.2-16.4
V	100	20-500	--	1,180
As	5	1-50	--	440
Be	6	--	--	--
Bi	1	--	--	--
Cd	0.5	0.01-0.7	.01-.43	51
Cs	5	0.3-26	--	27
Hg	0.03	0.03-0.3	--	--
Li	30	5-200	--	--
Ni	40	5-500	160-180	--
Pb	10	2-200	80-510	650

*From Baker and Chesnin, 1975

**Cope, F. 1961. The Agronomic Value of Power Station Waste Ash. Ph.D. Thesis, University of Leeds.

Table 2. Concentrations of ions as measured by the Baker soil test* in unweathered fly ash, fly ash weathered for two years, and soil material from the Station 1 disposal site.

	K	Ca	Mg	Na	Zn	Cu	Mn	Fe	Al	H_2O pH
	M x 10-4**				ppm*					
Unweathered fly ash	6.07	116.85	10.36	2.87	1.3	2.4	1.6	25.1	7.1	8.6
Weathered fly ash	3.03	64.89	9.97	2.87	0.6	1.0	1.6	23.5	5.5	--
Soil material	3.60	40.31	12.31	1.31	1.4	0.7	23.1	12.0	85.1	4.7

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*Calibration values for Baker soil test:

Low	<1.5	<40	<5	<2	<10	<10	<50	<25	<5	<5.5
Normal	1.5-4	40-60	5-16	2-10	10-75	10-40	50-100	25-75	5-20	6-7.3
High	>4	>60	>16	>10	>75	>40	>100	>75	>20	>7.3

**K, Ca, Mg and Na are expressed as concentrations in the small exchange extract and all others are amounts desorbed from the soil (solution concentration x 10).

unconsolidated regolith above the bedrock. The plots were 12 by 12m, seeded with several plant species and mulched with straw.

Initially the dominant plant species at the Station 1 test plots were sweet clover, tall fescue, and ryegrass. Birdsfoot trefoil became established on some plots the second year and gradually crown vetch became the dominant species. By the fall of 1976 a dense cover was established over all plots except on bare fly ash high in soluble salts and on soil materials high in coarse fragments. Several other vegetative cover experiments were conducted after the initial experiment, and it was shown that an adequate vegetative cover could be established on slopes of up to 9 percent and 200 ft long by mixing just enough soil into the fly ash to neutralize the excess CaO in the ash and bring the pH and electrical conductivity down.

Using the data from the Penn State studies, (Pannebaker 1981 and Lehrsch, 1981) and other data (e.g., Adriano et. al. 1980), the decision-making flow path and the criteria used are outlined graphically in figure 1. The manual prepared by GAI Consultants from this work was subsequently approved by PaDER for use at all such sites. Primary limitations to plant growth on fly ash (or fly ash-amended soils) identified early in the testing scheme are pH extremes, excessive levels of soluble salts, and excessive levels of boron (B) availability. The first two criteria are based on the report and experience at the Conemaugh location by Baker (1981) and coworkers. The boron criterion was based on the hot water soluble boron method and plant toxicity threshold reported by Adriano, et. al. (1980).

If the growing medium "fails" by the primary criteria, amendments can be considered to bring the resulting chemistry into a more favorable range. If the potential growing media considered are not toxic to plants based on the primary criteria described above, secondary tests for evaluating nutrient and trace/toxic element status of the growing medium are applied.

Secondary tests consist of the Baker test for available Ca, Mg, K, Fe, Mn, Cu, Zn, Na, Al, Pb, Ni, and Cd, plus conventional tests for oxalate extractable Mo and total Se. The latter two tests were based on concerns for excessive uptake of Mo and Se by plants. Neither Mo nor Se are toxic to plants, but excessive uptake of these elements by plants and subsequent consumption by foraging animals was a concern.

The methods described in the manual by GAI Consultants (1982) have been successfully applied by the consulting firm at at least seven permitted sites in Pennsylvania, and at one site each in Connecticut and Ohio. The analyses at each of these sites concluded in projects where 4 to 6 inches of soil, mixed into the surface 6 to 4 inches of fly ash, were used in lieu of 24 inches of soil cover. Sections of two of the fly ash sites were specified to be directly vegetated on fly ash without using any soil.

Revegetation success at fly ash disposal sites using these methods has led to adaptation of the methods to revegetation of coal refuse and steelmaking slag disposal sites using little or no soil cover. At four anthracite refuse sites the authors have designed revegetation plans using mixtures of fly ash and coal refuse in lieu of soil cover--with excellent results. Details of the analytical approach and results at the first of these sites are described in other reports (Buck and Houston 1988, Buck and Houston 1987, Buck 1987).

Monitoring

Monitoring of vegetation success and soil chemistry has been done for fly ash/soil mixtures and fly ash/coal refuse mixtures used in lieu of soil at these sites. The Baker test, 1:1 water pH, lime requirement by the SMP buffer method, oxalate extractable Mo, total Se, extractable B, and soluble salts assays were performed. In each case, the tests on laboratory mixtures of fly ash with soil (or coal refuse) adequately predicted the initial chemistry of the mixtures created in the field, as well as the suitability of the mixtures for plant growth (vegetation grew vigorously). The chemistry of field mixtures remained approximately the same over time with the exception of B, Mo, and/or Se. At fly ash disposal sites Mo and Se rapidly leeched out of the fly ash/soil surface (table 3), whereas over 3 years fly ash-amended anthracite wastes lost very little Mo and Se to leaching (Buck and Houston 1988, Buck 1987). Some extractable B weathered out of fly ash-amended coal refuse and fly ash/soil mixtures over time. Soil pH and Baker soil test parameters changed little, except for loss of excess Ca.

At the fly ash disposal sites, initial (laboratory mixture) Mo and Se levels in the alternative growing media were high which could preclude agricultural use of forages grown onsite, but less than 2 years of weathering reduced Mo and Se concentrations substantially. The soil chemistry results at the fly ash-amended coal waste site were followed up by plant tissue analyses for Mo and Se (Buck and Houston 1988, Buck 1987).

Concentrations of Mo and Se in plants grown on fly ash-amended coal refuse barely exceeded National Research Council (1980) guidelines for livestock rations,

Table 3. Summary of parameters of concern at the Station 2 disposal site.

Sample Description	pH	Saturation Extract Soluble Salts (EC, mmho/cm)	Saturation Extract Boron (ppm)	Hot Water Soluble Boron (ppm)	Total Selenium (ppm)	Oxalate Extractable Molybdenum (ppm)
Borrow Soil	5.0	0.80	<0.002	0.8	<0.5	<0.5
Unweathered Fly Ash	8.2	3.20	0.16	17.9	8.2	16.6
Lab 1:1 Soil:Ash Mixture	7.3	2.80	0.22	6.9	4.7	8.1
Lab 1:2 Soil:Ash Mixture	6.8	2.60	0.41	5.4	3.0	5.6
Weathered (Field) Ash/Soil (0-1.0' depth)	6.8	3.00	0.02	1.4	1.7	1.5
Weatherd (Field) Ash (1.0-2.0' depth)	8.2	2.10	0.15	5.5	2.7	4.2
Literature Toxicity Guidelines*	<4.0-5.5	>2-13	>1-15	>20.0	--	--

*Value ranges reflect species-specific tolerance ranges or differences in soil assay/plant uptake relationships due to soil type.

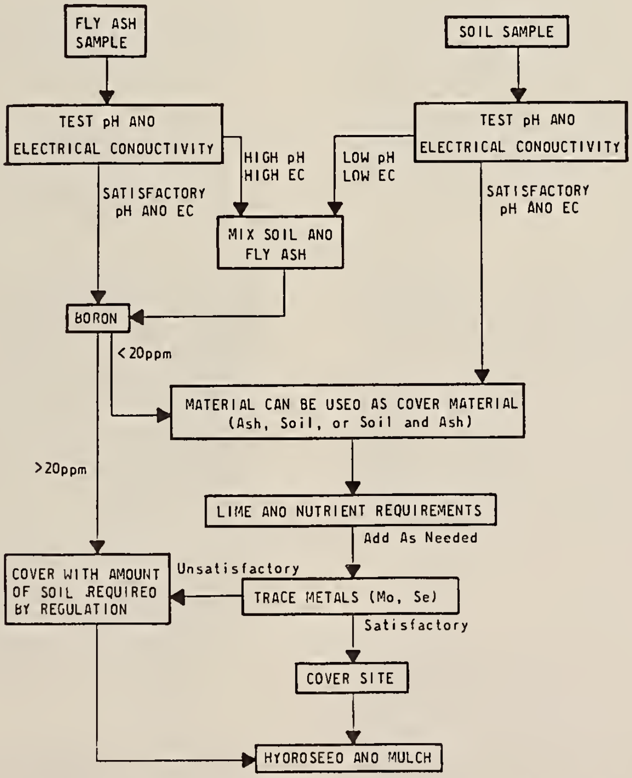
FLY ASH SAMPLE
SOIL SAMPLE
TEST pH AND ELECTRICAL CONDUCTIVITY
TEST pH AND ELECTRICAL CONDUCTIVITY
HIGH pH HIGH EC
LOW pH LOW EC
SATISFACTORY pH AND EC
SATISFACTORY pH AND EC
MIX SOIL AND FLY ASH
BORON
< 20ppm
MATERIAL CAN BE USED AS COVER MATERIAL (Ash, Soil, or Soil and Ash)
>20ppm
LIME AND NUTRIENT REQUIREMENTS
Add As Needed
COVER WITH AMOUNT OF SOIL REQUIRED BY REGULATION
Unsatisfactory
TRACE METALS (Mo, Se)
Satisfactory
COVER SITE
HYDROSEED AND MULCH

Figure 1. Flow chart to determine type of cover material at fly ash disposal sites (GAI Consultants, 1982).

confirming soil test expectations. Because livestock and wildlife do not intensively graze on the subject site, the magnitude of plant Mo and Se uptake was not a concern under that land use. All other elements tested in the normal or safe range for livestock forage.

Monitoring at sites where fly ash was used as an unconventional growing medium or soil amendment indicated that the Baker test, when used in conjunction with B, Mo, Se, pH, lime requirement, and soluble salts tests, adequately evaluated the suitability of the media used in lieu of soil as growing media. Weathering effects on Mo and Se were inconsistent, but other parameters remained the same or improved with time. These preliminary monitoring data suggest that changes in growing media chemistry over time may or may not improve the potential of an alternative growing medium to produce wholesome food or forage. Thus, changes in land use (such as a shift from wildlife habitat to agriculture) should be based on monitoring data, not assumptions, for trace elements of concern.

Refinement of Testing Methods and Interpretive Criteria

Experience of the authors and others has brought and will continue to bring about changes in methods and interpretive criteria. For example, most of the plant toxicity thresholds for salts, boron, etc. are based on soil concentrations which cause yield reductions, or visual symptoms of toxicity in agricultural crops. Soil conditions causing yield reductions with crops may still be adequate from most land reclamation perspectives. Yield reductions may be avoided via use of tolerant plant materials. The concept of yield adequacy must be refined to apply to post-reclamation land uses.

Increased sophistication in soil analysis must be continually incorporated into expert systems for land reclamation. For example, hot water soluble B assays are good to test for B-sufficiency (B is a plant micronutrient), but saturation extract B concentrations are better indicators of potentially phytotoxic soil conditions (Keren and Bingham 1985). Likewise, a modified Baker test (currently under investigation) may be a better measure of the threat of excess soil Mo and Se to foraging animals.

CONCLUSIONS

The decision-making flow path described in figure 1 and this text is an example expert system specifically designed to support evaluation of alternatives to soil as growing media at fly ash disposal sites. The expert system described here is based on the manual by GAI Consultants, Inc., (1982) and a unique approach to soil testing, the Baker soil test.

Monitoring the results from use of these methods at fly ash sites has been encouraging and has also pointed out the need for continual revision of methods and interpretive criteria as the state-of-art advances. The system used to evaluate growing media at fly ash disposal sites has been successfully adapted to meet other reclamation challenges (coal refuse and slag sites with little or no soil).

Computerization of this soil chemistry system and similar decision-making systems would have several advantages:

1. Like the manual form, computerized systems would introduce logical consistency to reclamation problem solving;
2. Monitoring methods, if integrated into the systems, can be used to test the strengths and weaknesses of the system, especially with regard to the ability of the system to predict the results of a land management technique;
3. Computerized systems are easy to revise as technology evolves (e.g., changing testing parameters, methods, and interpretive criteria);
4. Computerized systems can be easily expanded to handle new situations (e.g., soil salinization, smelter contaminated soils); and
5. Computerized systems can make the advice of "experts" more accessible to reclamation practitioners and regulators.

The Soil Conservation Service's Plant Adaption Data System (PADS) is an existing example of a successful computerized expert system for matching plant species with site conditions and land management goals. Although the examples discussed in this paper were confined to soil chemistry issues of concern to land reclamation, the potential scope of expert systems in land reclamation is unlimited.

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THE ROLE OF CORN VARIETY AND POPULATION IN MEETING TARGET YIELD LEVEL FOR PHASE III BOND RELEASE[1]

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Abstract. -- Two experiments were conducted in western Kentucky to evaluate the effects of varietal selection, plant population, and soil ripping on productivity of corn (Zea mays L.) growing on recently-reconstructed prime farmland. In Experiment 1, 3 corn hybrids with known maturities (full-season--125 days, mid-season--120 days, early-season--115 days) were planted at populations of 14,900; 19,000; 20,600; and 24,200 kernels per acre to form a 3 by 3 factorial treatment set. All treatment combinations were further split into ripped and nonripped variables. Four replications were used, and the experiment was conducted 3 consecutive years. The full-season hybrid was more productive than the mid-season hybrid, which was more productive than the early-season hybrid. The effect of population was somewhat variable, depending upon available soil moisture and/or precipitation. The highest overall average corn yield was attained at the highest population (24,200 kernels per acre). Soil ripping increased corn yield for each hybrid x population treatment each year. In a separate experiment, the productivity of 42 commercial corn hybrids available in western Kentucky was evaluated. This experiment indicated that yield of corn will vary considerably depending upon the hybrid used. Yields ranged from 104.3 to 64.4 bu/a, with 14 of the 42 hybrids exceeding the yield needed for Phase III bond release. There was a relationship between maturity date and yield in that early-season varieties generally produced higher yields than later-maturing varieties.

INTRODUCTION

Prime farmland (PFL) that is disturbed by coal mining operations must be restored to productivity levels that equal premining levels. Current regulations in Kentucky require that the productivity levels of PFL be achieved 3 consecutive years before release of (Phase III) reclamation bonds. For at least 1 of the 3 years, corn (Zea mays L.) must be planted. Success in producing corn yields on reconstructed PFL equal to or above that required for Phase III bond release has not been easily achieved, but has been realized with the use of proper soil reconstruction techniques (Barnhisel and Powell, 1985). Further improvement of corn yields on reconstructed PFL has resulted from proper fertilization, weed control, tillage, and organic amendments (Powell et al., 1986). In the above studies, the same corn hybrid was used.

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In addition to selecting the best tillage and fertilization practices, corn yields are affected by choice of hybrid, planting strategy, and pest control measures for site-specific conditions (Larson and Hanway, 1977). Preliminary data for soybeans (Glycine max (L.) Merr.) and grain sorghum (Sorghum bicolor (L.) Moench.) indicate large differences in yield among varieties of these species on restored PFL (Barnhisel et al., 1986). For example, yields from Group III soybeans were very poor as compared to Group V, although soybean cultivars from Group III are recommended varieties for non-mined PFL in this region of Kentucky. For reconstructed PFL, little if any information is available concerning either corn variety selection or planting population.

Compared to other crops, corn may have a more demanding water requirement (Barnhisel, 1983), but it is difficult to evaluate water requirements due to the differences among crop species for growing habits. Some crops such as corn and grain sorghum, C4 species, are approximately two times more efficient than alfalfa, a C3 plant (Gardner et al., 1985); however, the growing period for alfalfa is approximately 60 days longer than for corn, which affects how the efficiency rating is computed. Ground cover also affects these calculations. For example, alfalfa has a high percent ground cover throughout the growing season, whereas the percent ground cover for corn increases from 0 to 100% between planting and a week or two prior to silking. Both the planting date and choice of hybrid maturity are management inputs which can affect ground cover, water requirements, and grain yield of corn (Hanway and Russell, 1969).

Corn growing on reconstructed PFL will more likely be subjected to moisture stress than corn on natural soils. In general, low moisture availability will delay or reduce plant vigor. Three periods within the life cycle of corn are critical with respect to the final grain yield. During the first or vegetative growth stage, moisture stress may reduce development rates of leaves and ear primordia that would ultimately affect yield potential. If the stress occurs within 2 weeks of, anthesis (pollination) the second stage, serious yield reductions are also possible (Shaw, 1977). During this stage of growth, ovules and pollen mature, fertilization occurs, and maximum kernel number is determined. Water stress early in this growth period can delay ovule and/or pollen maturation which could cause reduced seed set (Schoper et al., 1986). Water stress later on in this period could cause premature kernel abortion or reduced growth rate of the kernel, which could reduce the size and/or number of mature kernels (Schoper et al., 1986; Quattar et al., 1987). The corn plant's development is timed so as to minimize this stress, since the root system develops to its maximum size during the tassel to pollination phase of growth (Mengel and Barber, 1974). In Kentucky, corn will enter into this growth stage approximately 70 to 90 days after planting. The last period is mid- to late-grain filling period, where moisture stress will reduce the size (weight) of individual kernels. If at any one of these periods moisture is limited for a few days, yields may be significantly reduced.

Management strategies should be based upon the best available information, since corn yields can be seriously reduced by minor variations of micro-climate when grown on reconstructed soils. These soils will, at least initially, possess unfavorable physical properties such as soil compaction and poor structure. The greatest consequence of excessive compaction is reduced infiltration and/or hydraulic conductivity and the subsequent reduced water holding capacity. Newly-reconstructed PFL will rarely have a soil structure that is sufficiently porous to allow plant roots to fully exploit an equivalent soil mass of a nonmined soil. Coincidental with the 70 to 90 days after planting, at a time when rainfall deficits are most likely to occur, corn in Kentucky will exhibit its highest water demand. At this time, average water demand for corn will be approximately 0.13 in./day, and on hot and windy days the water demand can exceed 0.25 in./day (Donway, 1971). This would be equal to one single corn plant utilizing 1/2 gal. of water/day.

Corn varieties normally available for general use in the humid regions of the U.S. are usually not specifically selected for drought resistance, although it is likely that some differences may exist. For example, it has been shown that corn hybrids containing male sterile cytoplasm can withstand water stress better than hybrids with normal cytoplasm (Vincent and Woolley, 1972). Drought resistance exhibited by a specific hybrid can also be confounded by other factors such as population, row width, and soil fertility (Larson and Hanway, 1977).

The plant density recommended for optimum corn yield tends to vary for areas within the Corn Belt as well as hybrid genotype. Many factors, including climatic variables and soil types, and there are used to match predicted growing conditions with the available hybrids. Experiments have been performed (on natural soils) in which corn yields were related to plant populations, but data for reclaimed PFL are not available. Plant populations may be varied by changing the number of kernels within the row or changing the row width. In general, yield will increase as row width is decreased from a range of 60 to 40 inches to 40 to 20 inches (Stickler, 1964). The higher yield of narrow-row corn is attributed to more efficient utilization of available soil water and greater solar radiation interception (Andrew and Peek, 1971; Demead et al., 1962).

From the above information, it seems reasonable to assume that any combination of treatments which would aid in maximizing the total rooting volume of reconstructed PFL would result in greater yield. Productivity might be further enhanced if more were known about optimum populations and hybrid selections for PFL. In addition, it is also possible that these factors may significantly interact. Lorens et al., (1987) found that the relative degree of drought resistance expressed by a specific corn hybrid was related to its ability to grow deeper root systems. With the above factors in mind, two experiments were designed with the following objectives:

1 Determine if hybrid selection for drought-prone, reconstructed PFL will favor hybrids of earlier of late maturity.
2 Determine if the optimum corn seeding rate for reconstructed PFL is different from that currently recommended for corn production on non-mined agricultural soils.
3 Evaluate whether subsoiling (ripping) reconstructed PFL results in different outcomes for objectives 1 and 2.
4 Evaluate whether reconstructed PFL alters the relative performance of 42 corn hybrids from that observed on non-mined agricultural soils.

METHODS AND MATERIALS

The experiments were conducted on two separate sites within 3/4 of a mile from each other on similarly reconstructed soils. The corn population-maturity date experiment was conducted on a block of PFL reconstructed in 1981, whereas the PFL for the corn variety experiment was reconstructed in 1983. Both experiments were located at Peabody Coal Company's River Queen Mine, Muhlenberg County, KY.

Experiment 1. Corn Population-Maturity Date

Reconstructed PFL for this experiment consisted of 10 inches of Ap horizon (topsoil) placed over 30 inches of a mixture of B and C horizon subsoil. The majority of the original soil was Waverly silt loam (coarse-silty, mixed, acid, thermic Typic Fluvaquent). Topsoil and subsoil had been stockpiled for a period of 14 months, and the soil was reconstructed using scraper pans. Following reconstruction, a good vegetative cover of tall fescue (*Festuca arundinacea* Schreb.), alfalfa (*Medicago sativa* L.), and red clover (*Trifolium pratense* L.) was established. This vegetation had been maintained on the site for two years prior to the establishment of the population-maturity date experiment in 1985.

A split plot experimental design with 4 replications was used. The area for each replication was 180 x 150 feet and was subdivided into 2 equal parts of 90 x 150 feet each. One split of each replication was ripped. Sufficient space was available within each split for three corn cultivars at four populations. Each treatment was 4 rows wide, with 8 border rows on all sides.

The ripping treatment was established in March of 1985. Ripping was performed on each appropriate area using a parabolic ripper operated at a depth of 20 inches with 30-inch spacing. The ripping treatment was repeated in the spring of 1987 on the same areas ripped in 1985. Duplicate, two-inch diameter core samples (6 inches in length) were collected from each treatment to a depth of 40 inches for bulk density determination.

The area was fertilized with P and K according to recommendations from soil tests, and ammonium nitrate was applied at 136 lb/a of N. Fertilizer incorporation and final seedbed preparation were accomplished by disking. A side dressing of ammonium nitrate was also applied in early June at 50 lbs/a of N.

The three hybrids used were: FR27 x PA91 (125-day maturity), FR27 x MO17 (120-day maturity), and FR27 x LH38 (115-day maturity), henceforth referred to as full-, mid-, and early-season, respectively. The planting populations were 14,900; 19,000; 20,600; and 24,200 kernels per acre. Planting was accomplished with a four-row, plateless, conservation planter with a 30-inch row spacing. Appropriate herbicides and insecticides were applied at planting using recommended rates.

Experiment 1 was conducted for three years. Each year the location of each corn hybrid-population treatment was randomly assigned. Planting dates were April 18, April 18, and April 10 for 1985, 1986, and 1987, respectively. Corn yields were determined by harvesting the two middle rows of each four-row plot with a small two-row, self-propelled combine. Grain weight and moisture content for each treatment were determined in the field. Yields are reported at the standard 15.5% moisture content.

Experiment 2. Corn Variety

The soil for this experiment consisted of 8 inches of Ap horizon replaced over 32 inches of a mixture of B and C horizon materials. The soil was reconstructed from separate topsoil and subsoil stockpiles which originated from Belknap (Coarse-silty, mixed, acid, mesic, Aeric Fluvaquent) and Sadler (Fine-silty, mixed, mesic, Glossic Fragiudalf) silt loam soils. The ratio of the reconstructed PFL soil was approximately 25% Belknap and 75% Sadler. These soil materials were replaced with scraper pans.

Permanent vegetation had not been established on this area, as was done in the case of the other experiment; however, the area had been used as a location for a soybean (Glycine max L. Merr.) variety trial the previous two years. The entire area had been ripped each year, as described for the population-maturity date experiment.

A lattice experimental design with four replications was used to evaluate 42 corn hybrids, identified later in table 4. The corn variety test was planted April 29, 1987. A two-row plot planter with a 36-inch row spacing was used to plant at a population of approximately 24,000 kernels per acre.

Lime had been applied at a rate of 1.5 t/a in 1984. Each year this area has received both P and K fertilizers according to recommendations from soil tests. In 1987, the N fertilizer, and weed and insect control treatments were identical to those used for the population-maturity date experiment. Yields were determined in a similar manner as in Experiment 1.

RESULTS AND DISCUSSION

Experiment 1. Corn Population-Maturity Date

Specific bulk density values are not reported were for the population-maturity date experimental site, even though soil ripping was one of the treatment variables. In general, soil ripping reduced bulk density by approximately 0.2 g/cm^3 to a depth of 18 inches as compared to the nonripped treatments. Although bulk density measurements were not made for these soils prior to mining, even the ripped treatment had a bulk density slightly greater than that reported for the natural Waverly soil series.

Corn yields as affected by maturity date, population, and soil ripping are shown in table 1. Considering the current Kentucky PFL regulations, composition of the original soil series, and allowable climatic adjustments, the target level yield for corn on this site is 81 bu/a. For the duration of the experiment, the target yield was exceeded only one time in three years when in 1985 the yield for the ripped treatment was planted to the full-season hybrid at 19,000 kernels per acre.

Although two of the standard corn hybrids used in this experiment i.e., FR27 X PA91 and FR27 X LH38, generally produce lower yields than most commercially-available hybrids, they serve as a basis to compare the effects of plant population and maturity. In 1985, there was a trend for the full-season hybrid to out-yield the other two hybrids, especially for the ripped treatment. In both 1986 and 1987, the maturity date of the hybrid did not consistently affect yield. In 1985, there was also a trend for the lowest corn population to produce less yield than the other three populations, but it rarely resulted in a significantly lower yield.

Ripping had the most consistent effect on corn yield. In both 1985 and 1987, ripping significantly increased yield for 11 of the 12 maturity-population treatments. This treatment resulted in an average increase in yield of 20 bu/a in 1985 and 25 bu/a in 1987. There were no significant interactions between ripping and either maturity or population. In 1986, the ripping treatment done in 1985 did not change corn yields, hence the plots were ripped again in 1987. This ripping treatment appears to have allowed for better exploitation of stored soil water by the corn roots.

The fact that corn yields were lower than the target yield each year, especially in 1986 and 1987, may be the result of below rainfall levels at this site. Table 2 shows rainfall data measured at a meteorological station approximately 1 mi. from the study site.

It is obvious that there were moisture deficiencies each month of each year, except June of 1986, which had a small excess (0.14 in.). Although 1986 was the best year with respect to precipitation received during the growing season (only a 1.75-in. deficit), the overall yields given in table 1 were lower than for the other two years. Since much of the rain that was received in June and July occurred as intense rain storms (unpublished data), it is likely that 1/2 of it was lost by runoff.

Peters and Bartelli (1958) reported that corn must make use of water stored in the top and subsoil because rainfall received during a season will rarely be adequate to produce average yields. Corn will withdraw water from a depth of about 30 inches in natural PFL. Elkins et al., (1961) reported that the average amount of stored soil water needed for acceptable corn production should be between 7 and 10 inches above that usually received as rainfall during the growing season. Soil moisture was not measured at this site; however at another experiment within 1/2 mi. there was less soil moisture available at the beginning of the 1986 growing season than for either of the other two years (unpublished data). This was due to lower than normal winter (1985-86) and spring (1986) precipitation. Therefore, the 1986 yields given in table 1 may actually represent performance under the "worst case" condition. Since soil moistures in 1985 and 1987 were near field capacity below a depth of 6 inches when the corn was planted (based on unpublished data from the adjacent site).

This experiment illustrates that even if when corn is grown under some moisture deficit, ripping will likely increase yield, as was observed between the ripped and nonripped treatments in 1985 and 1987.

Table 1.--Corn yield for years, 1985, 1986, and 1987 as a function of the maturity date, plant population, and ripping.

Maturity	Seeded	- - - 1985 - - -		- - 1986 - -		- - 1987 - -	
Date	Population	R*	NR*	R	NR	R	NR
		- - - - - - - - - - - - - - -	- - - - - -	bu/a	- - - - - -	- - - - - - -	- - - - - -
Full-season	14,900	71 BCD a**	53 BCDE b	39 E a	42 BCD a	67 A a	39 AB b
Full-season	19,000	88 A a	64 A b	46 CDE a	42 BCD a	64 A a	42 AB b
Full-season	20,600	78 ABC a	55 BC b	42 DE a	36 D a	66 A a	38 AB b
Full-season	24,200	80 AB a	59 AB b	45 CDE a	40 CD a	59 ABC a	40 AB b
Mid-season	14,900	67 CD a	56 BC b	45 CDE a	45 ABC a	64 A a	41 AB b
Mid-season	19,000	67 CD a	47 DEF b	48 BCD a	44 BCD a	51 C a	40 AB a
Mid-season	20,600	76 ABC a	47 DEF a	50 BC a	50 AB a	66 A a	40 AB b
Mid-season	24,200	72 BCD a	45 EF b	60 A a	52 A a	62 ABC a	34 AB b
Early-season	14,900	67 CD a	45 F b	43 CDE a	40 CD a	63 AB a	37 AB b
Early-season	19,000	69 BCD a	50 CDEF b	44 CDE a	42 BCD a	68 A a	36 AB b
Early-season	20,600	65 D a	57 AB a	44 CDE a	41 CD a	59 ABC a	32 B b
Early-season	24,200	70 BCD a	54 BCD b	54 AB a	44 BCD a	63 ABC a	44 A b

* R denotes ripped treatment. NR denotes Nonripped treatment.

** Numbers followed by same letter are not significantly different at the 90 % confidence level. Uppercase letters are for comparison within a respective column, whereas lowercase letters are for comparison between ripped vs. nonripped for a given year and treatment.

Table 2. Monthly precipitation and deviation from average for the growing season of each year.

		-----------	-----------	Year	-----------	-----------	-----------
Month	Avg.*	1985		1986		1987	
		(actual)	(+/-)	(actual)	(+/-)	(actual)	(+/-)
May	4.63	2.86	-1.76	4.57	-0.05	3.35	-1.27
June	3.60	3.31	-0.29	3.74	+0.14	3.16	-0.44
July	3.43	1.17	-2.26	3.14	-0.29	2.39	-1.04
August	3.05	2.14	-0.91	2.39	-0.66	1.00	-2.05
Total	14.71	9.48	-5.22	10.26	-1.75	8.03	-4.59

* Average monthly precipitation for Muhlenberg County. Data taken from the McLean-Muhlenberg County Soil Survey, USDA-SCS. p. 84.

Table 3. Average yield of corn over three years as a function of maturity date, population, and soil ripping.

	- - - - - - -	- - - - - - -	- - - - - - -	- - - - - - -	Population	- - - - - - -	- - - - - - -	- - - - - - -	- - - - - - -	- - - - - - -
Maturity	14,900		19,000		20,600		24,200		Ave.	
	R*	NR*	R	NR	R	NR	R	NR	R	NR
	- - - - -	- - - - -	- - - - -	- - - - -	bu/a	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -
Full	59	47	66	49	62	43	61	47	62	47
Mid	59	48	55	43	64	46	65	44	61	45
Early	58	41	60	43	56	43	62	47	59	44
Ave.	59	45	60	45	61	44	63	46	53	45

* R denotes ripped, NR denotes nonripped.

The absence of a yield advantage for ripping in 1986 could have been caused by the absence of this tillage treatment in 1986, as plots in 1986 were planted in the same areas as in 1985, or by the poor rainfall distribution.

Table 3 summarizes the effects of corn maturity, population, and ripping on corn yield averaged over all three years. In addition the advantage for ripped over nonripped, the yield rank from high to low was associated with maturity date since yield tended to decrease from full- to mid- to early-season hybrids. Such ranking, with an even greater advantage for full-season hybrids, would normally be expected for non-disturbed soils and normal growing seasons. In the 1987 Hybrid Corn Performance Test (Evans et al., 1987) at 7 locations, FR27 X PA91 yielded 3.4% more than FR27 X MO17 and 2.4% more than FR27 X LH38. Since the advantage of the full- over the early-season hybrid in this study was only 6%, it is likely that the full-season hybrid encountered more stress than the early-season hybrid in there reclaimed soils and suggests that proper selection of hybrid maturity and planting date could maximize yield production, particularly if one could predict the time of the drought stress. In western Kentucky, drought stress is more likely in late July and August; hence an early maturing hybrid may be able to avoid the moisture stress by producing more of its grain dry matter before the onset of drought. The planting dates for this experiment were relatively early (April 18, April 18, and April 10 for 1985, 1986, and 1987, respectively) and most likely did provide an advantage for the early hybrid. Since FR27 X LH38 was not developed for this southern production area and may not be adopted to the disease and insect problems oat this latitude, it is possible that other early-season hybrids may provide an even greater yield advantage.

For the ripped treatments, yield tended to decrease as population decreased. For the nonripped treatments, a similar order was observed. This ranking is similar to what one would expect from commercial hybrids, as most of them have been selected under high population densities. As with the plant maturity variable, it is likely that drought stress may have limited full expression of yield advantages for higher plant densities. Given the conditions expected to occur for reconstructed PFL, 20,000 kernels per acre may give maximum yields most years. If early hybrids are grown, a higher plant density than 24,000 may be needed to achieve complete ground cover.

Experiment 2. Corn Variety Experiment

Relative performance of 42 selected hybrids is reported in table 4. This data is only for 1987, since problems occurred in 1985 and 1986 that reduced our confidence in data for those years. The problems included low soil fertility, areas of high bulk density within replications, vandalism, and drought. Except for drought, most of the negative effects were eliminated or significantly reduced for 1987.

Also reported in table 4 are average performances of these varieties for 5 other Kentucky locations Evans, et al., (1987). The hybrids planted at the reclaimed PFL site are a subset of the 132 hybrids evaluated in the Prog. Rep. 308. When one considers the serious rainfall deficit of 1987 at the River Queen PFL site, the overall yields from this test were good. Based upon current regulations, the soil series that were a part of the reconstructed soil, and allowable climatic adjustments, the target level yield for phase III bond release is 81 bushels per acre. Fourteen of the 42 hybrids exceeded target level yield.

One must assume that part of the yield differences between the hybrids are due to drought tolerance. From Experiment 1, we concluded that at least part of the yield advantage for drought tolerant corn is that early maturing hybrids avoiding the of "normally occurring" drought in western Kentucky. Thus, in addition to the actual test results for yield, hybrid maturity may provide a second useful evaluation for hybrids to be used on reclaimed PFL sites. One can estimate, from seed moisture content at the time of harvest, the relative harvest maturity dates of the hybrids. We have included, for comparison purposes, in this River Queen variety test, three inbred lines of known maturity date. These same entries were also included in the University hybrid performance test.

The three hybrids in the University test had average harvest grain moisture contents of 15.8, 14.4, and 13.9 percent for full-, mid-, and early-season hybrids, respectively. Moisture contents of these hybrids in the River Queen test were 18.2, 15.4, and 11.9 percent, respectively. For each data set, i.e., River Queen and University Performance Tests, the mid-point between the moisture of each check hybrid was used to establish ranges in moisture content by which the known hybrids were grouped into three categories of "wet", "medium" or "dry" relative moisture at the time of harvest. For example, any hybrid with a moisture greater than 15.2 was placed into the "wet" group for the University data set. The average yield of each group was determined and these data are given in table 5.

There is a reversal between these two data sets. For reclaimed PFL, the early-season hybrids had higher yields than the later maturing hybrids; the opposite was true for the hybrids grown on natural soils. For droughty reclaimed PFL, earlier hybrids yielded more than later hybrids. For the University test group, where moisture conditions were much better, the rank was reversed. There was a major inconsistency for yields of the "standard" hybrids for the two experiments. The yield for the mid-season hybrid (FR27 X MO17) in Experiment 2 yielded significantly more than either the full- or early-season hybrids. Since this result was inconsistent with Experiment 1 results and the maturity groupings shown in table 5, it is possible that the high yield of FR27 X MO17 was an experimental error attributed to an anomalous genotype by environment interaction. Although the trends noted from Experiment 2 generally

Table 4. Yield and comparison of relative rank of hybrids tested at the River Queen site with results of the five western Kentucky sites of the University of Kentucky's statewide test[3] 1987.

PFL Rank	Corn Hybrid	-- River Queen --		five - W. KY Sites	
		Yield	Moisture	Yield	Rank
		bu/a	%	bu/a	
1.	McCurdy 7676	104.3	13.5	175.2	3
2.	Dennis DS642	97.8	13.8	168.7	6
3.	Coker 8696	95.0	17.6	*	*
4.	Asgrow/O's Gold 2570	93.7	13.4	164.1	13
5.	Colbert 345	92.4	17.9	168.5	7
6.	Zimmerman Z28	90.8	14.6	163.2	14
7.	Southern Cross 511	90.7	16.4	138.8	39
8.	FR27 X MO17	89.7	15.4	159.6	20
9.	Super Crost 5460	89.4	15.0	154.8	30
10.	Garst Seed 8344	88.3	14.9	150.3	34
11.	Princeton SX 860	88.3	15.4	136.5	41
12.	DeKalb-Pfizer DK 689	87.6	15.5	174.7	4
13.	Northrup-King PX 9581	86.9	20.3	156.5	26
14.	Prairie Stream SX 702	86.9	11.8	169.9	5
15.	Southern States SS 811	85.9	15.2	156.8	25
16.	Pioneer Brand 3320	85.8	13.6	165.3	11
17.	Select Seed 9131	85.3	15.1	165.3	11
18.	Agri-Pro HP 555	84.7	13.6	167.2	8
19.	Jacques 8700	84.1	19.1	162.9	15
20.	Crow's 688	83.5	14.4	149.1	37
21.	Agrigold A-6615	83.4	14.6	148.9	38
22.	Jacobi 8801	83.2	15.1	150.6	33
23.	Lynks LX 4533	82.9	14.9	152.8	32
24.	Stauffer S 7759	82.4	14.6	161.6	17
25.	Leader SX 717	82.3	14.7	149.9	36
26.	P.A.G. SX351	82.1	14.1	155.9	27
27.	Pioneer Brand 3165	81.7	14.8	182.8	1
28.	Becks 89X	79.8	13.7	155.1	29
29.	Golden Acres T-E 6998	79.7	19.0	177.0	2
30.	Funk's R.A. 1502	79.3	15.6	161.7	16
31.	Funk's G-4635	79.3	14.6	158.7	22
32.	Adlers 88X	79.1	18.9	166.5	10
33.	Southern States SX 728	78.8	13.5	152.9	31
34.	Bo-Jac 674	76.6	17.2	158.5	24
35.	Paymaster 8990	75.6	19.1	161.1	18
36.	Cargill 967	73.4	14.3	160.7	19
37.	Cargill 980	72.5	18.3	150.0	35
38.	Seedtec H-2675	72.2	15.2	158.6	23
39.	Agratech GK900	70.7	14.2	155.6	28
40.	FR27 X PA91	66.5	18.2	165.0	12
41.	D & H Seeds DH 9113	65.8	16.5	159.1	21
42.	FR27 X LH38	64.4	11.9	138.0	40
	$\bar{X}$ =	82.9	15.5	159.3	
	LSD$_{0.10}$ =	18.1	2.7	N.D.	

* 'Coker 8696' was a hybrid tested at the River Queen site but was not included in the University of Kentucky statewide test. (See Evans et. al., 1987).

support the conclusions based on data from Experiment 1, an additional two years of data should be obtained before these trends can be considered reliable indications of hybrid maturity responses on reclaimed PFL.

Table 5. Average 1987 yield of hybrids as "grouped" by maturity date estimated from grain moisture percentage at harvest.

Relative Moisture	River Queen	University
	- - - bu/a	- - -
Wet (Full-season)*	77.8	161.7
Medium (Mid-season)	85.0	158.4
Dry (Early-season)	86.9	157.4

* Maturity date estimated by grouping similar moisture content to moisture content of hybrids of known maturity date.

CONCLUSIONS

There is danger in making conclusions with one or even three year's data; however, to the best of our knowledge, this study provides the only data available for assistance in making corn production management decisions on reclaimed PFL soils. Our discussions of maturity date influences on PFL corn yield should be considered tentative, but promising, and should stimulate further research related to these types of management inputs. There are many studies that need to be done. For example, early-maturing varieties at the River Queen site produced high yields, but the planted population was held constant at 24,000. It is not known how the planting date will affect yields on reclaimed PFL. How should corn planted on PFL be adjusted to match the predicted drought period so as to increase chances of success for specific maturing hybrids? Would specific hybrids selected for drought tolerance be more suitable for corn production on PFL in Kentucky? Are the specific corn diseases or insects more influential on reclaimed PFL sites than on nonmined sites?.

Perhaps we have raised more questions than we have answered; however, from these experiments the following conclusions have been drawn:

1 High populations (approximately 24,000 kernels per acre) are better than low populations (approximately 14,000).
2 Soil ripping will increase corn yields on PFL regardless of hybrid used, maturity date, and population.
3 Commercially-available hybrids exceeded target level yield for corn, even during an extremely stressful year.
4 Relative yield ranking of corn hybrids evaluated on natural soils may not be accurate predictors of hybrid performance on reclaimed PFL soils.

The last conclusion may be the most important from a practical point of view of mine land reclamation. Prior research has shown that relative yield ratings for varieties of wheat (Triticum aestivum L.) were similar when grown on either reconstructed or natural soils (Powell et al., 1987). The same relationship appears to be true for grain sorghum and soybeans (Barnhisel et al., 1986).

Corn hybrids in our test did not follow this pattern. Further testing of corn varieties should be done to determine if our 1-year hybrid yield evaluation was adequate to evaluate PFL yield performance or to identify specific hybrids with a high degree of drought tolerance. Corn hybrids with this characteristic would increase the chance of success during the interim between soil reconstruction and the time it takes for the subsoil to develop desirable soil structure characteristics.

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EFFECT OF SOIL DEPTH, LIMING, AND SUBSOILING OF RECONSTRUCTED PRIME FARMLAND ON ALFALFA PRODUCTION.[1]

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Abstract. -- Differences in crop yield and bulk density were evaluated using two sites in Kentucky to study various soil depths and liming, subsoiling, and ripping treatments. The effect of soil moisture at the time of subsoiling was also evaluated. At the Alston Surface Mine site, alfalfa (Medicago Sativa L.) yields exceeded target levels for prime farmland Phase III bond release 2 of the 5 years. Liming the subsoil prior to replacement resulted in increases in alfalfa yields, whereas neither subsoiling nor alfalfa cultivar selection produced significant differences. In general, the highest alfalfa yields were from the shallowest soil depth treatments. All alfalfa yields from the River Queen Surface Mine site exceeded the target levels for Phase III bond release both years of this study. Soil moisture at the time the soil was ripped did not produce the expected results for either alfalfa yield or bulk density. Ripping and/or subsoiling had little effect on changes in soil bulk densities, and alfalfa yields were generally reduced by subsoiling.

INTRODUCTION

The passage of Public Law 95-87, the Surface Mining and Reclamation Act of 1977, was a complex piece of legislation which has affected every phase of surface mine reclamation. One aspect of this law and its ensuing regulations is restoration of prime farmland, which is the focus of the research data reported here.

It has been well established that subsoiling will reduce the bulk densities of soils used in agriculture (Akin, 1979; Allmuras et al., 1977; Barnes, et al., 1971; Henning and Colvin, 1977; Hodder, 1975; Olsen and Henning, 1980; and Trouse and Humbert, 1959). Subsoiling studies on restored prime farmland in Kentucky were conducted on the Alston Surface Mine, operated by Peabody Coal Co. in Ohio County. This was the first attempt to reduce the adverse effects of the increase in bulk density due to surface mining.

When the bulk density is increased to excessive levels, the growth rates of agronomic plants may be reduced. The term "excessive compaction" does not have a good working definition as it is not easily associated with an absolute value for all soil textures and moisture conditions.

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There is a lack of information as to how bulk density affects plant growth under field conditions. This problem is further complicated in that plants do not respond equally to a given set of bulk density conditions. Furthermore, differences in nutrient availability and other chemical properties may also interact with bulk density.

Many articles have been written on the effect that bulk density may have on plant root development (Carson, 1974; Lowry et al., 1970; Meredith and Patrick, 1961; Russell, 1977; Taylor and Gardner, 1963; Viehmeyer and Hendrickson, 1948; Wali and Sandoval, 1975; and Zimmerman and Kardos, 1961). Any increase in bulk density potentially reduces plant growth; this applies not only to soils affected by surface mining, but also to naturally-occurring soils that may have higher than desirable bulk densities.

The minimum depth of soil necessary to achieve post mining productivity equal to that before mining is an item needing further clarification even though several studies have been conducted on this topic (Deane, 1977; Farmer et al., 1974; Nielsen and Miller, 1980; Power, 1978; Power et al., 1981; Russell, 1977; Sandoval and Gould, 1978; Sindelar et al., 1973; Taylor and Gardner, 1963; and Zimmerman and Kardos, 1961). The crop being grown strongly influences the topsoil depth requirement as do the chemical, physical, and mineralogical nature of the spoil material underlying the topsoil. When spoil materials have good properties that do not restrict root growth, less topsoil is needed to provide a rooting media for optimum crop production (Grandt, 1978), if it is needed at all.

Over the past 10 years, six projects have been initiated in western Kentucky related to restoration of the productivity of prime farmland. This paper is to address only a very small part of this research which was conducted with the following objectives: (1) To determine the effect of soil depth, subsoil liming, and subsoiling on alfalfa yield; and (2) To determine the effect of soil moisture, at the time subsoiling was performed, on alfalfa growth and changes in bulk densities.

MATERIALS AND METHODS

Alston Site

Plot Construction

Three test plots with varying subsoil depths were established at this site following mining. Prior to this, the topsoil (A horizon), approximately 20 cm thick had been removed from two soils by scraper-pans and placed into a stockpile. About 75% of the area had been mapped as Sadler (Glossic Fragiudalf, fine-silty, mixed, mesic) and the remainder as Belknap (Aeric Fluvaquent, coarse-silty, mixed, acid, mesic). Approximately 80 cm of subsoil (B and C horizons) was also removed from these two soils and placed into a separate stockpile.

After the coal had been removed, the overburden spoils were graded and two areas of subsoil were replaced with scraper-pans, one at each of two depths, 40 and 80 cm. Each area of subsoil was at least 75 by 100 m. In addition, one area of graded spoils with the same approximate size was established. The surface of all these plots had a slope of 2%. These three plots were sub-divided into 2 areas, each 75 by 50 m; and to one of each, lime was applied at a rate of 45 Mg/ha. The entire plot area was disked twice to a depth of 15-20 cm with a heavy-duty disk. Following this operation, 20 cm of topsoil was placed on all three of the main plots.

Fertilization

Agricultural limestone was applied to the topsoil of all three main plots at a rate of 11.2 Mg/ha. Phosphorus and potassium were applied at 100 kg/ha, P and K, respectively, and all materials were incorporated by disking. Nitrogen was applied to all plots being seeded except alfalfa.

Subsoiling

Subplots, 7.3 by 11 m in size, were established for each of the three test crops with four replications each. These subplots were further divided in half (3.7 by 11 m), and one-half of each subplot was subsoiled with a straight-shank subsoiler with a 90 cm spacing to a depth of approximately 50 cm. Assignment of the locations of the test crops and subsoiling was made randomly. The test crops used were corn (Zea mays L.), soybeans (Glycine max (L.) Merr.), and alfalfa (Medicago Sativa L.), however, data for only alfalfa are reported here. The borders separating plots were seeded to tall fescue (Festuca arundinacea Schreb.).

Alfalfa Seeding and Management

Two cultivars of alfalfa, 'Apollo' and 'Vernal', were broadcast in midApril 1979 at a rate of 26 kg/ha. The position of each cultivar was assigned randomly on each subsoiled subplot. A cultipacker was used to provide soil-seed contact.

In 1979 two alfalfa cuttings were made, one in late July and the other in September. In the following four years (1980-1983), the first cutting was made in May at the 50% bloom stage, with subsequent harvests every 35 days until the fall months. This management allowed at least 4 harvests each year.

At each harvest, the alfalfa forage from a known area was collected with a rotary mower at a height of 7.5 cm. and the fresh weight determined to the nearest

10 g. Small subsamples were taken from each plot with electric hand clippers. These samples were placed into sealed plastic bags and weighed in the field with a battery-operated digital balance to the nearest 0.01 g. The subsamples were then frozen with dry ice for transport to the laboratory, where they were maintained at -12°C until removed from the freezer for drying at 60°C. The moisture lost was used to calculate oven-dry hay yields from the lawn mower clippings. The dried alfalfa samples were ground to pass a 40 mesh screen. These samples were used for all chemical analyses.

In early March of 1980 and 1982 soil samples were taken from each alfalfa plot for soil tests. Based on these data, P and K fertilizers were applied to each sub-plot at recommended rates based on tables in AGR-1 (Agronomy Staff, 1979). In general, the soil test data resulted in recommendations ranging for P of 40 to 50 kg/ha and 70 to 90 kg/ha for K.

River Queen Site

Plot Construction

A large area of reconstructed prime farmland was selected from a part of the general reclamation of the mine. The soil had been replaced as two horizons with scraper-pans. The thickness of the topsoil and subsoil materials was approximately 20 and 90 cm, respectively, and each had been stockpiled for at least 18 months. This area was divided into blocks; the size of each varied in width as required to accommodate each of the five test crops, but all were 150 m long. Data for only alfalfa will be given here from the area 15 by 150 m.

Ripping

The entire block of replaced prime land was treated as a unit. The five test crops were the main blocks, with the ripping treatments randomly assigned in each sub-block with four replications each. The ripping treatments included a control (nonripped) and ripping performed at three soil moistures.

Ripping was done using a three-shank parabolic ripper, pulled by a dual-wheeled, four-wheel drive tractor, at a depth of approximately 60 cm. One sub-block was ripped when the soil was dry, approaching the wilting point of this soil. The next ripping treatment was done when the soil was at the midpoint between field capacity and the wilting point, and the last treatment was ripped at a soil moisture near field capacity.

Alfalfa Fertilization and Management

Soil samples were taken for estimation of lime, P, and K needs. Tables in AGl-1 (Agronomy Staff 1979) were used for lime recommendations to raise the pH to 6.8, and for P and K. The alfalfa test area was seeded in the spring of 1984 using the 'Vernal' cultivar at a rate of 26 kg/ha. Soil samples were also collected in mid-March of 1986 from each treatment and appropriate levels of P and K applied.

Since there was less than adequate precipitation, harvests were not made in 1984. In 1985 and 1986, the first cutting was taken in May and subsequently every 35 days through September. A self-propelled forage harvester was used to collect forage from areas of each plot. Hand-clipped samples were taken as described earlier for the determination of oven-dry weight hay yields.

Soil Testing Methods

Soil Bulk Densities

Soil core samples (5 cm O.D.) were taken to the soil-spoil interface. These cores were first divided into 15cm segments, then trimmed to a flat surface on both ends, measured to the nearest 0.05 mm, placed in a plastic bag, and sealed for transport to the laboratory. The percent soil moisture and ovendried weight (100°C) of each core was determined. The bulk densities were expressed on a dry weight basis and soil moisture expressed on a volume basis.

Chemical Properties

Exchangeable cations, pH, Bray-1P, and lime requirement were determined by methods published in Black et al. (1965). The cations extracted with 1N NH_4OAc were determined with an atomic adsorption instrument. The pH's were measured in a 1:1 weight to volume of soil and distilled water. The lime requirement method was that proposed by Shoemaker et al. (1962), and phosphorus requirements were determined by the method described by Bray and Kurtz (1945).

RESULTS AND DISCUSSION

Alston Site

Data from the chemical analyses of the alfalfa forage are not reported since none of the treatments resulted in significant differences in chemical composition. There was a trend for the plots in which the subsoil had been limed to be slightly higher in Ca and lower in Total N. These data were collected to insure us that the differences in yields were not the result of differences in soil fertility as well as to confirm we were applying adequate P and K.

Effect of Soil Depth.

Three soil thicknesses were evaluated at the Alston site: 20, 60, and 100 cm of soil over graded overburden. Alfalfa yields were taken for 5 years, and these data are given in table 1. Significant differences in yields were obtained, but

Table 1.--Effect of soil depth and subsoil liming on alfalfa yield, averaged across subsoiling and cultivar subtreatments.

Depth/Lime*	Harvest Year				
	1979	1980	1981	1982	1983
cm	(kg/ha)				
20 NL	3650 b B†	4610 bc B	6740 b A	7825 b A	4425 b B
20 L	4070 a D	5955 a C	7125 ab B	8260 a A	5510 a C
60 NL	2790 d C	4155 d B	6720 b A	7065 c A	4470 b B
60 L	3920 ab C	4880 b C	7100 ab B	8345 a A	4450 b C
100 NL	3205 c B	4375 cd B	7375 a A	8435 a A	4040 b B
100 L	2870 d B	4230 c AB	6905 ab A	8245 a A	3525 c B

* Total soil depth, L = subsoil was limed, NL = subsoil was not limed.

† LSD (0.10), lowercase letters are for comparisons between treatment means for a given year, whereas, uppercase letters are for comparisons between years for any given treatment.

Table 2.--Effect of subsoiling and cultivar on alfalfa yield, for averaged soil depth and subsoil liming treatments.

Subtreatment	Harvest Year				
	1979	1980	1981	1982	1983
	(kg/ha)				
1*	3510 a D†	4765 a C	7140 a A	8190 a A	4375 a
2	3110 ab D	4610 a C	6945 ab B	8080 a A	4915 a
3	3360 ab D	4695 a C	6890 ab B	7890 a A	**
4	3015 b D	4450 a C	6520 b B	7840 a A	**

* 1 = Apollo, subsoiled; 2 = Apollo, non-subsoiled; 3 = Vernal, subsoiled; and 4 = Vernal, non-subsoiled.

† LSD (0.10), lowercase letters are for comparisons between subtreatment means for a given year, whereas, uppercase letters are for comparisons between years for any given subtreatment. Comparison between years for 1983 data was not included.

** In 1983, the effect of cultivars was not evaluated, data given represent averages of both, as cultivars were harvested together.

they were not consistently related to soil depth. The highest yield was obtained from the thinnest soil treatment the first and second years. In 1981 and 1982, the yield from the limed treatments for all three soil depths was not significantly different, with the deepest (nonlimed) soil having the greatest numerical value. The last year alfalfa was grown, the largest yield came from the shallow soil treatment, and in this case, lime had been incorporated into the spoils prior to topsoil replacement.

The target yield for alfalfa for the soils used in this study is 6,665 kg/ha for prime farmland and 6,000 kg/ha for non-prime cropland. The first 2 years neither target level was exceeded; however, in 1981 and 1982, all treatments surpassed the prime farmland target value.

Effect of Subsoil Liming

Liming the subsoil prior to topsoil replacement produced significant yield responses for 7 of the 15 possible pairs or treatments. However, alfalfa yields for the deepest soil treatment which the subsoil had been limed were significantly lower in 1979 and 1983 than the nonlimed treatment. There is a possibility that this reversal was related to the plot position that alfalfa occupied, in which 2 of the 4 replications were near an active haul road. These plots may have received dust from this road, although for the most part the road was kept "watered" and the prevailing wind direction would have carried dust away from the experimental area.

The subsoil lime treatment resulted in significantly higher levels of exchangeable Ca and lower exchangeable acidity in the upper 15 cm of the subsoil (data not given). All other chemical properties were not significantly related to the experimental treatments.

Effect of Cultivars

The two cultivars established were 'Apollo' and 'Vernal'. 'Apollo' is more disease resistant, especially to root rot, and is also believed to be more acid tolerant than 'Vernal'. However, when yield comparisons were made (table 2), only small differences in yield were observed and in no cases were these significant. On an average, 'Apollo' outyielded 'Vernal' by 200 kg/ha.

Effect of Subsoiling

Data for comparisons of subsoil treatments are also given in table 2. Although the subsoiling treatment produced higher yields, in none of these cases were the differences significant. The difference in yield due to subsoiling was also about 200 kg/ha.

The bulk densities of the two soils prior to disturbing are given in table 3. These data were collected on sites adjacent to the area, since the topsoil and subsoil horizons had been stockpiled prior to initiation of the study. The Sadler soil had a somewhat higher bulk density in the Btx horizon, typical of fragipan soils.

Table 3.--Bulk densities* of the Sadler and Belknap soils prior to being disturbed.

Soil	Horizon	Bulk Density
		(Mg/m^3)
Sadler	Ap	1.40
"	Bt	1.53
"	Btx	1.62
Belknap†	Ap	1.42
"	Cl	1.54
"	Cg	1.50

* These data are from typical sites in the area, as samples were not collected prior to surface mining.

† Series name changed at Alston site to Stendal after field correlation.

Density data taken approximately one month after the soil had been replaced are given in table 4. The bulk density for both the topsoil and subsoil materials had been increased from 0.1-0.3 Mg/m^3. There were decreases in bulk density after one year for both the topsoil and subsoil materials, as given in table 5. The largest decrease was for the topsoil, which was most likely the result of the tillage operation associated with seedbed preparation. The decrease in bulk density for the 3045 cm sampling depth was likely the result of both subsoiling and root growth.

Extensive bulk density sampling was performed (spring of 1984) after the last year alfalfa was grown, and these data are given in table 6. The bulk densities were generally higher than those shown in table 5 and nearer those given in table 4, especially for the subsoil materials. In other words, it would appear that none of the treatments (subsoiling, liming the subsoil prior to topsoil replacement, nor growing alfalfa for 5 years) caused major reductions in bulk density. Unfortunately, direct statistical analyses between data collected in 1978 and 1984 cannot be made due to differences in sampling frequencies; however, it is speculated that the change in bulk density of the topsoil would reflect a significant decrease, whereas the bulk densities for the two lower depths were not different.

Table 4.--Initial bulk densities at the Alston Surface Mine site.

Depth*	Sample depth in cm 0 - 15	30 - 45	45 - 60
(cm)	- - - - - - -	(Mg/m^3)	- - - - - -
20	1.54 a †	- - -	- - -
60	1.55 a B	1.71 a A	1.73 a A
100	1.63 b B	1.67 a A	1.71 a A

* Data averaged across lime subsoiling treatments.

† LSD (0.10), lowercase letters are for comparisons between treatment means within a given sampling depth, whereas, uppercase letters are for comparisons between sampling depths for a given soil depth treatment.

Table 5.--Bulk densities at the Alston Surface Mine site after 1 year.

Depth*	Sample depth in cm 0 - 15	30 - 45	45 - 60
(cm)	- - - - - - - -	(Mg/m^3)	- - - - - -
20	1.45 a †	- - -	- - -
60	1.42 a B	1.58 a A	1.64 a A
100	1.40 a B	1.59 a A	1.66 a A

* Data averaged across lime subsoiling treatments.

† LSD (0.10), lowercase letters are for comparisons between treatment means within a given sampling depth, whereas, uppercase letters are for comparisons between sampling depths for a given soil depth treatment.

Extensive bulk density sampling was performed (spring of 1984) after the last year alfalfa was grown, and these data are given in table 6. The bulk densities were generally higher than those shown in table

5 and nearer those given in table 4, especially for the subsoil materials. In other words, it would appear that none of the treatments (subsoiling, liming the subsoil prior to topsoil replacement, nor growing alfalfa for 5 years) caused major reductions in bulk density. Unfortunately, direct statistical analyses between data collected in 1978 and 1984 cannot be made due to differences in sampling frequencies; however, it is speculated that the change in bulk density of the topsoil would reflect a significant decrease, whereas the bulk densities for the two lower depths were not different.

RIVER QUEEN SITE

Data from the chemical analyses of the alfalfa forage from this experiment are not be reported since they are similar to the other site and none of the treatments resulted in significant differences in chemical composition. These data were collected to insure us that the differences in yields were not the result of differences in soil fertility as well as to confirm we were applying adequate P and K.

Significant differences in the soil chemical properties did not occur at this location as a result of subsoiling, hence these data are not given.

Table 6.--Effect of soil depth, subsoil liming, and subsoiling on bulk densities averaged across alfalfa cultivars after 5 years.

Depth/Lime*	Subsoiled	Non-Subsoiled
(cm)	(Mg/m^3)	
	0 - 15 cm	
20 NL	1.49 a A†	1.47 b A
20 L	1.55 a A	1.54 a A
60 NL	1.51 a A	1.57 a A
60 L	1.50 a A	1.52 ab A
100 NL	1.52 a A	1.59 a A
100 L	1.54 a A	1.58 a A
	30 - 45 cm	
60 NL	1.75 a A	1.69 ab A
60 L	1.75 a A	1.69 ab A
100 NL	1.71 a A	1.79 a A
100 L	1.67 a A	1.58 b A
	45 - 60 cm	
60 NL	1.72 a A	1.62 b A
60 L	1.75 a A	1.62 b A
100 NL	1.71 a A	1.71 a A
100 L	1.72 a A	1.75 a A

* Total soil depth, L = Limed subsoil; NL = Not Limed subsoil.

† LSD (0.10), lowercase letters are for comparisons between treatment means within a given subsoiling treatment and within a single depth, whereas, uppercase letters are for comparisons between subsoiling treatments for a given depth and lime treatment.

Effect of Subsoiling

The alfalfa yields as a function of the soil moisture at the time the ripping was performed are given in table 7. Surprisingly all the ripping or subsoiling treatments significantly decreased alfalfa yield. The treatment which was believed to be the most beneficial, i.e., ripping under a dry condition, actually gave the lowest yield both years. In fact in 1986, the yield for this treatment (dry ripping) was significantly lower than for all other treatments.

The target yield for alfalfa (6,665 kg/ha) was exceeded both years for all treatments and represent a high production level for agricultural soils in western Kentucky. These high yields were the result of "ideal" management practices and the fact that rainfall distribution in 1985 and 1986 was reasonably good, unlike the lower than normal precipitation levels for the establishment year, in which harvests were not made.

Bulk density data collected after 6 and 42 months are given in table 8. Data from the surface or topsoil horizon were somewhat erratic. The bulk density from the control or nonripped treatment for the first sampling had the lowest value, whereas this same treatment had the highest bulk density at the end of the experiment. Some of these treatments produced significant differences with time. For example, the bulk density from the control plots and intermediate treatments increased from 1.45 to 1.69, and 1.55 to 1.60 Mg/m^3, respectively.

Table 7.--Alfalfa yields as a function of soil moisture at the time time plots were ripped.

Moisture Condition	Harvest Year 1985	1986
	(kg/ha)	
Dry	8350 b A†	7960 c B
Intermediate	8770 b A	8605 b A
Wet	8725 b A	8640 b A
NonRipped	9420 a A	9300 a A

† LSD (0.10), lowercase letters are for comparisons between treatment means for a given year, whereas, uppercase letters are for comparisons between years for any given treatment.

For the 30-45 cm depth of sampling, ripping did not produce any significant differences at either the 6- or 42-month sampling periods. The difference in bulk density from the two extreme treatments was only 0.05 Mg/m^3 for either sampling. The only significant change that was observed was for the nonripped treatment, which increased in bulk density between the first and second sampling. The reason for changes in bulk density between these two or for any of the sampling dates is unknown. For the 45-60 cm depth, changes in bulk density were positive in two cases, i.e., dry and intermediate treatment, and negative for the nonripped control.

Table 8.--Bulk densities from alfalfa plots after 6 and 42 months as a function of soil moisture at the time plots were ripped.

Moisture Condition	Time after ripping 6 mo.	42 mo.
	- - - - - Mg/m^3	- - - -
	- - - - 0 - 15 cm	- - - -
Dry	1.56 a A†	1.52 b A
Intermediate	1.55 ab B	1.60 ab A
Wet	1.58 a A	1.58 b A
NonRipped	1.45 b B	1.69 a A
	- - - - 30 - 45 cm	- - - -
Dry	1.69 a A	1.68 a A
Intermediate	1.64 a A	1.66 a A
Wet	1.67 a A	1.70 a A
NonRipped	1.65 a B	1.72 a A
	- - - - 45 - 60 cm	- - - -
Dry	1.65 c B	1.81 a A
Intermediate	1.72 bc B	1.78 a A
Wet	1.76 ab A	1.73 a A
NonRipped	1.82 a A	1.78 a B

† LSD (0.10), lowercase letters are for comparisons between treatment means for a given year, whereas, uppercase letters are for comparisons between years for any given treatment.

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A SUBSTITUTE TOPSOIL PLAN FOR RECLAMATION OF A MOUNTAINTOP REMOVAL MINE IN SOUTHERN WEST VIRGINIA[1]

Lawrence D. Emerson[2]

Steep topography and thin native soils in the Southern Appalachian coalfields present special problems in reclaiming large surface mines. By investigating geologic core logs or highwall samples, certain strata can be targeted for use as an alternative topsoil material. A mining plan was developed to recover three coal seams and reclaim with a mudstone-sandstone mixture. The substitute topsoil tested high in calcium, magnesium, and potassium with pH readings ranging from 6.2 to 7.2 standard units. A 72-yd.^{3} dragline removed most of the overburden and deposited it in the previous pit. The spoil piles were then regraded to their final postmining topography. To facilitate revegetation of the gently rolling plateaus to hay and pasture land, a two-step seeding plan was devised. The regraded mudstone-sandstone spoil was initially seeded in an annual grass-legume mixture to provide quick erosion control. After one growing season, the annual cover was turned under with a heavy-duty offset disk harrow. The initial cover acted as a "green manure" to enhance nutrient and water-holding capacities of the new minesoil. The cultivated area was then reseeded in a timothy-alfalfa mixture providing a local source of quality hay and grazing land.

INTRODUCTION

Successful revegetation of large surface mines in southern West Virginia is largely dependent on the availability of enough quality topsoil to cover the regraded area so that the approved postmining land use can be achieved. In most areas, the native soils are thin, acidic, and highly weathered. Average slopes over much of the southern coalfields exceed forty percent. In some cases, however, the nature of some overburdens is conducive to plant growth. A careful examination of the physical and chemical characteristics of the mudstones and sandstones overlying the coal seam may provide useful information in determining if an alternative soil material is present. By identifying such formations, a reclamation plan was developed to utilize a topsoil substitute that is in many ways superior to that of native soils. Soil management techniques were used to enhance

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the water-holding and nutrient exchange capacities of the developing minesoil so that the approved postmining land use could be realized.

TOPSOIL SUBSTITUTION PLAN

An approved topsoil substitute plan is currently in use at the Hobet Mining Number 21 Surface Mine located in Boone County, WV. The operation lies within the Allegheny and Kanawha geologic formations in the southwestern part of the state. Most of the production is from the Five Block (Lower Kittanning) and Upper and Middle Stockton Coal Seams. Occasionally some Middle Kittanning Coal is found on the highest ridgetops. The lithology of the area is predominantly light gray sandstone and gray mudstone with some weathered brown sandstone occupying significant areas on ridgetops and points. A relatively continuous rider seam lies some 10 to 15 ft. above the Upper Stockton Seam.

The mine plan utilized a 27-yd.^{3} electric shovel and rock truck spread to remove the overburden from the mountaintop down to the Five Block Seam. This material was placed in end-dump, durable rockfills. A flat area was left after the coal was removed, providing a working space for a 72-yd.^{3} walking dragline. The dragline then removed approximately 100 ft. of overburden to uncover the Stockton Seams. This overburden above the Stockton Seams is comprised of about 75 ft. of gray sandstone and 25 ft. of gray mudstone. Most of the mudstone lies directly above the Upper Stockton. As the dragline excavated, the sandstone was deposited in spoil piles in the preceding pit. The mudstone was removed last and placed on the top and sides of the spoil piles. The spoil piles were then regraded, leaving a mixture of gray sandstone and mudstone on top.

Minesoil Analysis

The Acid-Base accounting of core logs that is required in the permit application provided general guidelines as to the type, location, and paste pH of the overburden. This information was useful in determining which strata would best be suited for further sampling and testing. The highwall was sampled when accessible and correlated with additional samples after regrading (Sobek et al. 1978). Test results of the substitute material appear in Table 1. Native soil test results are shown for comparison. (Laboratory methods used are according to Sobek et al. (1978).

Table 1.--Nutrient and texture analyses of substitute topsoil and native soil materials.

Soil Characteristic	Topsoil Substitute	Native Soil
Nutrient analysis, lb./acre:		
P	< 1.0	7.6
K	297	127
Ca	3,100	60
Mg	600	40
Lime required, ton/acre	0	3.2
pH	6.7	4.6
Texture analysis, percent:		
Sand	64.3	56.8
Silt	21.2	21.8
Clay	14.5	21.4
Texture class	Sandy Loam	Sandy Clay Loam

In comparing the test results, it is clear that the substitute material is superior to the native soil in nearly all aspects with the exception of phosphorus and clay content.

Experience at this site has shown that the data derived from the Acid-Base accounting proved effective in determining the best available substitute minesoil.

Soil Management Practices

The objective of the reclamation plan was to reclaim the flat to gently rolling areas of the mine site to hay and pasture land. Since the substitute topsoil was generally low in clay content, it was determined that the limiting factors in establishing a productive pasture cover were water-holding and nutrient exchange capabilities of the material.

To reduce these deficiencies, a two-step seeding process was developed. In the fall or early spring, the plateaus were fertilized and hydroseeded in a seed mixture designed to provide quick erosion control that later was tilled in as green manure. This initial seeding served two important purposes. First, to incorporate the organic matter in the substitute material in order to increase nutrient and water-holding capacities. Second, to allow the material to weather through several freezing and thawing cycles to help break up larger stones. The following seeding season, this initial cover was turned under with a heavy-duty offset disk harrow.

After cultivation, the area was again fertilized and reseeded in a permanent hay and pasture mix. Those areas too steep for cultivation were seeded in a herbaceous mixture and developed into a wildlife or forest land postmining use. The disk harrow is a heavy-duty

Table 2.--Species used in two-step seeding process.

Hay and Pasture Mix

Species	Application (lb./acre)
Alfalfa	18
Birdsfoot Trefoil	18
Timothy	12
Perennial Rye Grass	18
Orchard Grass	36
Mammoth Red Clover	18

Green Manure Mix

Species	Application (lb./acre)
For Fall Seeding:	
Hairy Vetch	80
Annual Rye Grass	40
For Spring Seeding:	
Yellow Sweet Clover	50
Annual Rye Grass	70

Fertilizer

Type	Application (lb./acre)
15-30-15	400

model specifically designed for highway or construction use. This particular model has a 15-ft.-wide cut. It has 28 disks, each 32 inches in diameter, made of one-half inch hardened steel and weighing 500 lbs. Disk penetration of 8 to 10 inches was common in the regraded mudstone material. Many large stones were crushed and broken up by the slicing action of the disks; complete turning under of the green manure crop was realized. The disks were pulled by a D-8 bulldozer or equivalent. The pasture mix and green manure mix consisted of the species listed in Table 2.

RESULTS AND CONCLUSIONS

The primary objectives of disking in the cover crop were to enhance the ability of the developing minesoil to hold water and nutrients so that the permanent vergetation could become established. As the alfalfa-orchard grass cover matured, the roots would be able to penetrate deep enough so that soil moisture would not be critically limited during extended dry periods. Also, natural recycling of nutrients from decaying matter would help resupply the root zone with nitrogen and phosphorus.

Although there has been no actual soil testing to verify that the cation exchange or the water-holding capacities have been improved, the density and drought resistance of the vegetative cover is readily apparent. Ground cover in most areas is 90 percent or greater. Root penetration has been seen to exceed 24 inches. The summer of 1987 was exceptionally dry with only 0.65 inches of rainfall from July 15 to September 4. The alfalfa or orchard grass stand was dormant during this time but grew vigorously with a soaking rain. Total height of the stand exceeded 18 inches.

In areas where native soils are scarce or infertile, an alternative strata can be utilized to create a new soil that is capable of supporting vegetation. With proper management, such a minesoil can sustain grasses and legumes and provide quality forage to local cattle-raising efforts.

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AN EVALUATION OF METHODS FOR DETERMINING PASTURE AND HAY PRODUCTION ON RECLAIMED SURFACE MINES[1]

J. G. Skousen[2]

Abstract--Before releasing a reclamation bond, regulatory agencies must estimate plant cover and aboveground biomass on the reclaimed site and compare it to a reference area to determine if acceptable vegetation exists. While most state regulatory agencies have adopted some method for measuring plant cover, no state has adopted a method for measuring vegetative or forage production (aboveground biomass). Nine methods for evaluating plant cover, composition, and aboveground biomass were selected to determine which, if any, of the methods would provide a simple, unbiased, repeatable, and accurate way of assessing aboveground biomass. Five of the methods involved visual estimation of certain plant parameters (Rennie-Farmer Cover, Quadrat Cover, Grass %, Legume %, Estimated Yield, and Quadrat Height), two methods indirectly measured aboveground biomass (Disk Meter and Probe), and one method directly measured aboveground biomass by clipping small plots (Quadrat Weight). The five visually-estimated methods were almost always significantly different among three observers when done on eight reclaimed sites in West Virginia. The vegetation on these sites differed in the amount of dead plant material, and species composition and density. Because of the unique characteristics of the vegetation on each site, some methods provided better estimates of aboveground biomass on particular sites than other methods. Quadrat Height (average height of the vegetation), Quadrat Weight (the weight of clipped forage in quadrats), and the Disk Meter were the three methods that showed high correlation with large clipped plots (Transect Weight). Estimated Yield showed good correlation to Transect Weight, while Rennie-Farmer Cover, Quadrat Cover, Grass %, Legume %, and the Probe showed poor correlation to Transect Weight. Since the Disk Meter correlated well to the weight of forage in mowed transects and does not involve visual estimation, it should be studied in more detail as a method for evaluating aboveground biomass on reclaimed surface mines.

INTRODUCTION

Revegetation Standards

Standards for determining successful revegetation of mined lands are set by Federal regulations as follows: "Success of revegetation shall be judged on the effectiveness of the vegetation for the approved postmining land use, . . . Ground cover, production, or stocking shall be considered equal to the approved success standard when they are not less than 90 percent of the success standard. The sampling techniques for measuring success shall use a 90 percent statistical confidence interval (i.e., one-sided test with a 0.10 alpha error). For areas developed for use as grazing land or pasture land, the ground cover and production of living plants on the revegetated areas shall be at least equal to that of a reference area or such other success standards approved by the regulatory agency." (USDI 1983)

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Evaluation of Ground Cover

By law, ground cover by plants must be measured for evaluating revegetation success on mined lands. Various methods are used by states with approved regulatory programs. The Office of Surface Mining Reclamation and Enforcement (OSMRE) conducted a field study to evaluate eight methods of determining ground cover (OSMRE 1987). Most of the methods used in the study were those that are approved in state regulatory programs in the eastern United States. The researchers found that all eight methods gave similar results. Some of the methods, however, were simpler and easier to understand than others. While the researchers did not make specific recommendations, it appears from their study that parts of different methods could be combined to increase sampling accuracy, precision, and effectiveness. The method for evaluating ground cover in West Virginia is called the Modified Rennie-Farmer procedure (explained in Methods), and has several advantages: 1) the method is simple, 2) the data are collected quickly, 3) the results are easily calculated, and can be analyzed statistically.

Evaluation of Plant Biomass

Determining aboveground biomass of plants on reclaimed land is a difficult task for regulatory agencies. Measurement of plant aboveground biomass is usually accomplished by clipping all the plant material in plots of predetermined dimensions (25 x 25 cm, 1 x 1 m, etc.). The plant material is placed in a paper bag, dried in a forced-air convection oven at 60°C to a constant weight, and weighed. The estimate of aboveground biomass is calculated by converting the dry weight of the material in the plot to kilograms per hectare. By clipping numerous plots, an average weight per unit area and a standard error can be calculated to determine the accuracy and precision of the sampling technique. This method has long been an accepted and effective practice for measuring aboveground biomass in hay fields, pastures, and rangeland.

Even though widely-used and accepted, clipping plots for estimating aboveground biomass by regulatory agencies has several disadvantages in terms of inspection and enforcement of laws related to revegetation of surface-mined lands. The three largest disadvantages of the method are: 1) the time required to clip 25 to 50 plots is excessive (this number of plots is usually necessary to obtain an adequate statistical sample), 2) the labor involved is intensive, tiresome, and tedious, and 3) special facilities are needed to dry and weigh the plant material.

An approach developed to reduce the time and effort required to clip all plots involves visually estimating the weight of aboveground biomass followed by clipping and weighing a portion of the plots. Typically, the worker estimates the weight of ten successive plots. After the visual estimate is made on the 10th plot, the worker "calibrates" his estimates by clipping and weighing the aboveground plant material in the plot. The value determined by clipping and weighing is compared to the estimated value, and the worker then makes adjustments to his estimates. By routinely clipping every 10th plot and "calibrating" the weight estimate, many individuals can become quite proficient in making reasonably accurate weight estimates. Others, however, are never quite able to make weight estimates with any degree of reliability (Mueller-Dombois and Ellenberg 1974, Stoddard et al. 1975). This method is particularly difficult for individuals who do not use it frequently. In the case of surface mine inspection, estimating forage biomass once or twice a month (even with calibration clippings) would produce results that would be variable, and possibly refutable by the coal operator.

An approach for measuring aboveground biomass without clipping plots is the disk meter (Baker et al. 1981). The governing principle of the disk meter is that aboveground biomass is highly correlated with height and density of the vegetation. The disk meter consists of a circular board or steel plate (up to 80-cm diameter) which freely slides up and down on a steel pipe. When the disk meter is dropped from a standard height onto the vegetation, the board is supported by the vegetation and its height on the steel pipe is measured. A limited number of plots are clipped and regression equations then relate the height of the disk meter to aboveground biomass.

Baker et al. (1981) studied the use of the disk meter on 40 mixed swards cut for hay in West Virginia. They divided the swards into 14 different categories corresponding to different proportions of grasses, legumes, and weeds in the sward. The researchers reported the slopes of the regression lines for the different categories were not significantly different. However, questions have been raised concerning the disk meter's suitability for measuring aboveground biomass on mined lands. Mined lands produce vegetation with wide variations in species composition, density and height.

Palazzo and Lee (1986) used two different sized disk meters (45 and 60 cm diameter) to predict plant biomass of a pure stand of K-31 tall fescue (Festuca arundinaceae Schreb.) and a pure stand of sericea lespedeza (Lespedeza cuneata (Dumont) G. Don.) on reclaimed mined lands. The disk meter height to biomass weight relationship was highly variable, and was best within individual sampling days. Across all seasons, the linear correlation (r) between disk meter height and biomass was 0.61 for lespedeza stands and 0.78 for tall fescue stands.

Capacitance meters have been used for biomass estimates for many years and are another method for measuring aboveground biomass. These meters are based upon electrical principles. The term "capacitance" describes the amount of electrical charge stored by two conductors (or plates) separated by an insulator (or dielectric). The amount of capacitance is determined by the surface area of the conductors and the resistance of the insulator.

The Pasture Probe™ is a portable, microprocessor-controlled capacitance meter, designed to measure and record pasture biomass in practical field applications (Design Electronics LTD 1985). In the Pasture Probe™ the central earth spike and the outer aluminum tube are the two plates of the capacitor, and the air and the perspex spacer (in the aluminum tube) form the dielectric. The device introduces an electric charge (or capacitance) into the circuit. An air reading provides a reference level of capacitance against the reading of the probe when it is placed on the ground. Changes in capacitance (due to the surface area and amount of green vegetation and biomass) cause the frequency of the signal to change. The change in frequency is converted to biomass through mathematical relationships.

Two recent studies (Crosbie et al. 1985, Richardson 1984) have been conducted with the Pasture Probe™. Crosbie et al. (1985) compared the Pasture Probe™ with other direct and indirect methods of measuring dry matter and reported the following conclusions:

1) the probe readings were sensitive enough to delineate between pasture grazing treatments;
2) the precision of the probe was at least as good as that of other methods currently used;
3) large labor savings were evident when the probe was used instead of direct methods such as mowing and quadrat cutting.

There is a need to assess the use of direct (quadrat clipping) and indirect methods (cover estimates, height estimates, biomass estimates, disk meter, and Pasture Probe™) in measuring aboveground biomass on surface-mined lands. In order to demonstrate the application, effectiveness, and accuracy of these methods in predicting aboveground biomass on surface-mined lands, a research project was conducted using eight reclaimed sites in WV. The objective of this investigation was to determine the precision and suitability of each technique for predicting aboveground biomass in order to assist regulatory agencies in determining revegetation success and granting bond release.

MATERIALS AND METHODS

Study Sites

Eight surface-mined areas in West Virginia were selected as research sites based on location, coal seam, overburden, date mined and reclaimed, mining method, length of time since seeding, and revegetation techniques (lime, fertilizer, and seeded species). This was done to obtain a cross-section and variety of mined areas and reclamation techniques.

Sampling Methods and Analyses

Four transects of 100 m were randomly located on each site. Every 10 m along the transect, eight measurements or estimates were made by three observers. Each observer carried a separate data sheet for recording estimates, and no discussion took place during visual estimates (methods 1 through 5). The observers were agronomy and forestry graduate students with good backgrounds in plant identification. The measurements were made in the following order.

1) Rennie-Farmer Cover

A round, 1-cm diameter, 113-cm long dowel with 20 equally-spaced ring marks was placed perpendicular to the transect line and inserted into the vegetation. Each of three observers recorded the number of "hits" at each sampling point. A hit occurred when living vegetation was found directly above, below, or touching the mark on the dowel. A count of 20 was possible at every sampling point.

2) Quadrat Cover

A quadrat measuring 50 x 50 cm (0.25 m^2) was placed on the left side of the transect line, and each observer visually estimated the total amount of plant cover in percent.

3) Quadrat Botanical Composition

In the same 0.25 m^2 quadrat as in (2), each observer estimated the botanical composition. The categories were Grass %, Legume %, and Weed %.

4) Estimated Yield

In the quadrat, each observer visually estimated the fresh weight of the plant material inside the quadrat. (After the material in the quadrat was clipped as described in Method 8, the fresh plant material in every third quadrat was weighed with a portable scale and observers were able to "calibrate" their visual biomass estimates).

5) Quadrat Height

A meter stick was placed in the center of the quadrat which each observer used to estimate the average height of the vegetation in the quadrat.

6) Pasture Probe™ Reading

Pasture Probe™ readings were taken in 10 places in a systematic grid pattern within each quadrat which gave an average corrected meter reading for each quadrat. This average reading was recorded.

7) Disk Meter Reading

The disk meter (50-cm diameter) was placed in the center of the quadrat and dropped onto the vegetation. The height of the disk was recorded in cm.

8) Quadrat Weight

After all estimates and readings had been taken, all biomass 1 cm above ground level in the quadrat was clipped and placed in a labelled paper bag.

A 65-cm wide swath of vegetation was mowed at approximately 1 cm above ground level along each 100-m transect line with a sickle-type mower. The plant material mowed in this swath was raked together and placed in labelled gunny sacks. The weight of forage collected in these mowed transects (called Transect Weight) was used as the target weight or control to which all other methods were evaluated.

All plant material clipped in quadrats or mowed along transects was transported to large drying ovens and dried at 60°C for 3 to 4 days and weighed to determine dry weight.

Cover, botanical composition, height and yield estimates by each observer were analyzed by analysis of variance to determine the variability among observers for estimated parameters (Rennie-Farmer Cover, Quadrat Cover, Grass %, Legume %, Estimated Yield, and Quadrat Height). After analyzing for differences among observers, the estimates were averaged for each quadrat and the average value for each visually estimated method were combined into a data set with the other methods (Pasture Probe™, Disk Meter, and Quadrat Weight) for analysis of variance, multiple regression, stepwise regression, and correlation with Transect Weight. The analysis was conducted using the Statistical Analysis System (SAS) at West Virginia University.

RESULTS AND DISCUSSION

Differences between three observers was significant with most methods and on many of the sites (table 1). The methods showing the least variation among observers in this study were the estimates of Grass % and Quadrat Cover. The methods that produced the most variable values among observers were Quadrat Height and

Table 1--Significance of differences between three observers in their visual estimates of cover and aboveground biomass using six methods on each reclaimed site.

	Site							
Method	CM	DP	GR	GS	KK	LR	HD	HO
Rennie-Farmer	NS[1]	**[2]	*	**	**	NS	*	**
Quadrat Cover	NS	*	**	NS	**	NS	NS	NS
Grass %	NS	NS	NS	NS	NS	NS	*	NS
Legume %	**	NS	NS	*	NS	*	**	**
Estimated Yield	**	**	*	*	*	**	**	NS
Quadrat Height	**	**	*	**	**	**	**	**

[1] Values estimated by three observers were not significantly different between observers.

[2] Values estimated by the three observers were significantly different at $p < 0.05$ (*) or $p < 0.01$ (**).

Estimated Yield. Since the vegetation on the sites differed in the amount of standing dead plant material, dead plant material lying on the ground, and the composition and density of living vegetation, it is not surprising that variation was high among observers. This finding demonstrates that visual estimates (even when looking at the same vegetation in a particular plot) are highly variable among individuals. Considerable variation existed even when the observers had good scientific backgrounds.

Because characteristics of the vegetation were different for each site, each method was independently compared to Transect Weight on each site (table 2). Some methods on certain sites predicted Transect Weight well, while other methods did not. For example, aboveground biomass as determined by mowing on Camden (CM) was best predicted by Estimated Yield, Quadrat Weight, and the Disk Meter. Prediction of Transect Weight by these methods on Gumspring (GS) was similar to CM. However, no method adequately predicted Transect Weight on Dippel (DP) and Laurita (LR). Five methods correlated well with Transect Weight on the Hodrag (HO) site. Estimated Yield, the Disk Meter, and Quadrat Weight correlated well with Transect Weight on three sites, while Rennie-Farmer Cover, Quadrat Height, and the Probe correlated well with forage weight in mowed transects on two sites.

Table 3 shows a matrix of partial correlation coefficients (r) between each pair of methods. There are several meaningful relationships. For example, the data show a high correlation (.74) between Estimated Yield and Quadrat Height. Other high positive correlations involve Quadrat Height with the Disk Meter (.67), and with Quadrat Weight (.70). The Disk Meter and Quadrat Weight are also related (.63). Estimated Yield is also related to Quadrat Weight (.68).

In order to find an appropriate method of measuring aboveground biomass for bond release, it is critical that the method be applicable to a wide range of sites. It has already been shown that only three methods correlated well with Transect Weight on three or more sites. It is important to determine the relationship of each method to Transect Weight across all sites.

Quadrat Height, Quadrat Weight, the Disk Meter, and Estimated Yield show high correlation with Transect Weight in this study (table 4). Although the correlation coefficient (r) for each of these four methods is 0.80 or higher, a demonstration calculating predicted values of aboveground biomass and its variation for several of the methods should be done, and compared to actual Transect Weight.

The equations are taken from table 4.

Predicted aboveground biomass = 982.4 + 296.7 (Quadrat Height)

Predicted aboveground biomass = -439.4 + 792.1 (Disk Meter Height)

Predicted aboveground biomass = -5213.6 + 135.7 (Quadrat Cover)

Calculating aboveground biomass is based on the average value across all sites and are 20.5 cm Height, 9.5 cm for Disk Meter. and 90.4% on Quadrat Cover. Predicted biomass values are 7065, 7085, 7053 g/transect, respectively. Multiplying these numbers by .15385 will convert from g in

Table 2--Coefficient of determination (r^2) between the values from each method for predicting aboveground biomass and the weight of forage in mowed transects (Transect Weight) on each reclaimed site.

	SITE							
Method	CM	DP	GR	GS	KK	LR	HD	HO
Rennie-Farmer	.41	.42	.96**[1]	.54	.41	.35	.89*	.37
Quadrat Cover	.50	.63	.40	.67	.01	.36	.90*	.50
Grass %	.23	.40	.03	.56	.60	.14	.24	.08
Legume %	.23	.33	.95**	.65	.25	.28	.16	.11
Estimated Yield	.94**	.77	.01	.43	.11	.47	.83*	.92*
Quadrat Height	.59	.54	.02	.79*	.01	.21	.33	.99**
Probe	.70	.62	.01	.22	.88*	.24	.46	.92*
Disk	.78*	.52	.11	.95**	.01	.16	.61	.97**
Quadrat Weight	.85*	.23	.01	.99**	.06	.68	.74	.98**

[1] The r^2 value is significant at this site at $p < 0.05$ (*) or $p < 0.01$ (**).

Table 3--Matrix of partial correlation coefficients (r) between each pair of methods for predicting aboveground biomass across all sites.

	Partial Correlation Coefficients[1]								
	Methods								
Method	RF	QC	G%	L%	EY	QH	P	D	QW
Rennie-Farmer (RF)	--	.68	-.07	.13	.26	.26	.37	.27	.29
Quadrat Cover (QC)	.68	--	-.14	.16	.51	.47	.40	.45	.50
Quadrat Grass % (G%)	-.07	-.14	--	-.87	-.11	-.05	-.05	-.05	-.08
Quadrat Legume % (L%)	.13	.16	-.87	--	.18	.08	.09	.02	.07
Estimated Yield (EY)	.26	.51	-.11	.18	--	.74	.43	.59	.68
Quadrat Height (QH)	.26	.47	-.05	.08	.74	--	.35	.67	.70
Probe (P)	.37	.40	-.05	.09	.43	.35	--	.35	.37
Disk (D)	.27	.45	-.05	.02	.59	.67	.35	--	.63
Quadrat Weight (QW)	.29	.50	-.08	.07	.68	.70	.37	.63	--

[1] Any partial correlation coefficient value greater than .113 is signiicant at the $p < 0.05$, and .148 is significant at the $p < 0.01$.

the transect to kg/ha, or 1087, 1090, and 1085 kg/ha, respectively. Confidence intervals associated with each regression equation (using the standard error for the intercept and slope) can be calculated. Once a range is calculated, the assumption is made that a particular method will predict Transect Weight at some level of confidence. For example, using the data collected from these eight sites and with a value of 20.5 cm in Quadrat Height, aboveground biomass will fall between 6588 to 7542 g/transect (1013 to 1160 kg/ha) 90% of the time. Calculating 90% confident intervals gives ranges of (using the same mean values for Disk Meter and Quadrat Cover as above), 990 to 1190 kg/ha for the Disk Meter, and 581 to 1629 kg/ha for Quadrat Cover. By comparison, the mean value for Transect Weight across all sites was 7085 g/transect or 1085 kg/ha.

A statistical procedure called Stepwise Regression (using the Statistical

Table 4--Correlation coefficients (r) between each method for predicting aboveground biomass and Transect Weight across all sites, and the linear regression equation associated with each method.

Method	r	Significance[1]	Intercept	STD Error of Intercept	Slope	STD Error of Slope
Rennie-Farmer	.43	*	-10454.3	6744.7	920.5	353.6
Quadrat Cover	.44	*	- 5213.6	4582.2	135.7	50.4
Grass %	.04	NS	6739.3	1714.2	5.6	28.6
Legume %	.02	NS	7159.8	1078.3	-2.9	26.9
Estimated Yield	.82	**	2071.6	710.2	34.2	4.4
Quadrat Height	.87	**	982.4	686.9	296.7	31.0
Probe	.51	*	771.6	1993.4	46.2	14.2
Disk	.84	**	-439.4	923.8	792.1	92.8
Quadrat Weight	.85	**	1811.0	659.0	122.2	13.9

[1] Significance is at $p < 0.05$ (*) or $p < 0.01$ (**) or not signficant (NS).

Analysis System) was used to find which one or combination of methods best predicts Transect Weight. The forward selection technique in the Stepwise Regression analysis begins with no variables in the model. For each independent variable (the various methods) the analysis calculates the variable's contribution to the prediction equation when included. This analysis then adds the variable that removes the greatest amount of variation. The independent variables (or methods) are added sequentially until no variables remain (Ray 1982).

The analysis showed that 75% of the variability in Transect Weight could be explained by determining the average Height of the vegetation (table 5). Rennie-Farmer Cover was next in the model and contributed only 4% more to the prediction of Transect Weight beyond Quadrat Height alone. Quadrat Height measurements varied widely among observers (table 1) and across sites (table 2), so it was removed as a variable. Quadrat Weight was then selected by the Stepwise procedure. Clipping plots, even small quadrats, for assessing revegetation success by regulatory agencies has several disadvantages as noted earlier, so Quadrat Weight was also removed from the variable list. Stepwise then selected the Disk Meter which accounted for 70% of the variation in Transect Weight across all sites.

SUMMARY AND CONCLUSIONS

When estimating vegetation parameters in the same 0.25-m^2 quadrat, three observers were almost always significantly different in their estimates which demonstrates that visually estimated techniques for assessing aboveground biomass are highly variable. Two cover estimation

Table 5--Stepwise selection of methods used in this study to predict Transect Weight.

Variable	Number of Variables in Equation	Partial R^2	Total R^2	Significance[1]
1. Quadrat Height	1	.753	.753	**
2. Rennie-Farmer	2	.040	.793	*
3. Quadrat Grass %	3	.032	.825	*
4. Quadrat Yield	4	.023	.848	NS
5. Quadrat Weight	5	.009	.857	NS
6. Probe	6	.004	.861	NS
7. Disk	7	.003	.864	NS
8. Quadrat Cover	8	.001	.865	NS
9. Quadrat Legume %	9	.000	.865	NS

Same analysis except without Quadrat Height

Variable	Number of Variables in Equation	Partial R^2	Total R^2	Significance[1]
1. Quadrat Weight	1	.721	.721	**
2. Quadrat Yield	2	.064	.785	**
3. Disk	3	.050	.835	**
4. Quadrat Legume %	4	.018	.853	NS
5. Probe	5	.005	.858	NS
6. Quadrat Cover	6	.002	.860	NS
7. Rennie-Farmer	7	.002	.862	NS
8. Quadrat Grass %	8	.001	.863	NS

Same analysis except without Quadrat Height and Quadrat Weight

Variable	Number of Variables in Equation	Partial R^2	Total R^2	Significance[1]
1. Disk	1	.708	.708	**
2. Quadrat Yield	2	.125	.883	**
3. Quadrat Legume %	3	.017	.850	NS
4. Probe	4	.004	.854	NS
5. Rennie-Farmer	5	.001	.854	NS
6. Quadrat Cover	6	.001	.855	NS
7. Quadrat Grass %	7	.001	.856	NS

[1] Significance is at $p < 0.05$ (*), $p < 0.01$ (**), or not significant (NS).

methods (Rennie-Farmer Cover and Quadrat Cover) did not correlate well with mowed transects except on one site. Estimating Grass % or Legume % was not as highly variable among observers as other estimation methods, but the methods also did not correlate with the mowed transects. Estimated Yield and Quadrat Height (both estimated by observers) were the two most variable methods among observers, but were two of the four best methods used in this study to predict Transect Weight. Quadrat Weight (clipping small quadrats) showed good correlation to Transect Weight. The Pasture Probe™ showed poor correlation to Transect Weight. The Disk Meter showed good correlation between its height and the weight of vegetation mowed in transects. Since the Disk Meter does not involve visual estimation and high observer variability, it should be studied in more detail as a method that may be adopted for aboveground biomass evaluation on reclaimed surface mines.

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THE BENEFICIAL USE AND DISPOSAL OF COAL ASH ON ACTIVE MINE SITES IN PENNSYLVANIA[1]

John W. Smith[2]

Abstract.--Recent statutory and regulation changes of the Department of Environmental Resources have affected the disposal or beneficial reuse of fly ash in Pennsylvania. Act 168, which became effective February 12, 1987, partially deregulates the beneficial reuse of fly ash. While Department approval is still required for a beneficial reuse, the formal permitting procedure has been eliminated. Through changes in Departmental Policy, the permitting procedure for fly ash disposal on mine sites has also changed. When the fly ash disposal site is located on an active mining permit, the responsibility for permitting and inspecting the site has been transferred to the Bureau of Mining and Reclamation (BMR). Surface mining sites, coal refuse disposal sites, and coal refuse reprocessing sites are the three types of mining sites where ash disposal or beneficial use can take place. As of December 1987 the BMR had issued 12 fly ash disposal permits and 2 beneficial use approvals. The number of sites permitted is expected to increase substantially in the future.

INTRODUCTION

Pennsylvania produces approximately 6 million tons of fly ash annually from coal-burning power plants. In addition, the "haul back" of fly ash from out-of-state power plants has the potential for further increasing the total volume of ash that must be disposed of in Pennsylvania. Pennsylvania also has over 17,000 acres of refuse banks left over from previous deep mining and preparation plant operations. This coal waste is suitable for burning in modern fluidized bed combustion (FBC) boilers. Recent changes in the Public Utility Regulatory Policy Act, favorable tax advantages for waste to energy plants, along with improved technology for coal waste-fired energy projects, have made these unsightly coal waste piles an important source of energy and economic development for the coal regions of Pennsylvania. Fly ash disposal has created environmental questions regarding the location and method of fly ash/bottom ash disposal or beneficial reuse. Active mine sites have been shown to be acceptable locations for both beneficial reuse and disposal (Capp, 1978). The Department's permitting process makes a distinction between beneficial reuse of fly ash, which requires Departmental approval, and fly ash disposal, which requires a formal permit. Permitting and approval of fly ash disposal sites and beneficial reuse of fly ash is the responsibility of the Pennsylvania Department of Environmental Resources (D.E.R.).

FLY ASH DISPOSAL

The Bureau of Mining and Reclamation has been delegated authority for the permitting and inspecting of fly ash disposal sites, when the disposal takes place at an active permitted mine site. The program is administered using the Solid Waste Management Act and corresponding rules and regulations (Chapter 75). This program applies to active surface mine sites, coal refuse disposal sites, and coal refuse reprocessing sites (Program Guidance Manual).

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Disposal is incidental to the mining operation, and the following restrictions apply to surface mine sites: 1) maintaining the approximate original contour in final reclamation; 2) the volume of ash being disposed of cannot exceed the volume of coal removed; 3) the operator must maintain concurrent backfilling; 4) the ash must be non-polluting; and 5) disposal is prohibited from sites that could be potentially sensitive to ash disposal. Sites on public water supply recharge areas, high quality watersheds, and sites with acidic overburden or underlying deep mine discharges generally are not acceptable for disposal. Abandoned pits can be permitted for ash disposal if the area is included on the active surface mine permit area and it can be shown that adequate reclamation of the affected area, including existing spoil ridges, can be achieved. The use of abandoned pits allows for both environmentally acceptable disposal and reclamation of these unsightly areas.

The disposal of fly ash on coal refuse disposal sites is limited to sites where fly ash is less than 50% of the total disposal volume. Fly ash disposal may be permitted at coal refuse disposal sites with collection and treatment of leachate or sites utilizing natural soil attenuation. Sites utilizing soil attenuation depend on the cation exchange capacity of the soil to tie up any metals in the leachate.

The disposal of fly ash on coal refuse reprocessing sites is limited to sites where there will be no increase in the total volume of material on site, and no reconstruction of large surface piles. The ash and the disposal location must also be environmentally acceptable.

PERMITTING PROCESS

The permitting process that is followed for fly ash disposal is an extension of the mining permit application procedure. An additional module (number 25), to be completed along with the mining permit application, has been developed and includes information on the chemical characteristics of the ash, its leachability, an operation plan for the disposal area, and ground water hydrology and quality information. Table 1 lists the required solids analysis and typical bituminous fly ash values. The EP Toxicity Extraction Procedure, which simulates an acid environment, is used to analyze the leaching potential of a particular waste stream. While no laboratory test procedure can exactly duplicate field conditions, the EP Toxicity Test simulates disposal that would occur in an acid environment possible on mine sites. Actual field conditions could produce leachate at higher or lower concentrations (L.L. Labuz, 1986). Table 2 lists the required leachate analysis parameters for the EP Extraction Procedure.

Table 1

Table 1.--Listing of parameters to be included in the ash chemical analysis of solids, with typical bituminous fly ash values.*

Parameter	mg/kg
Aluminum	140,000
Arsenic	175
Barium	900
Boron	300
Cadmium	10
Chromium	225
Iron	125,000
Lead	200
Manganese	350
Mercury	0.5
Nickel	250
Selenium	145
Copper	200
Molybdenum	50
Zinc	300

*adapted from Adriano, et al. 1980., L. L. Labuz, et al. 1986., and D. W. Weeter and M. P. Bahor 1979.

Table 2.--Listing of parameters to be included in ash leachate analysis (mg/l).

pH
Cyanide
Sulfate
Phenolics
Aluminum
Antimony
Arsenic
Barium
Boron
Cadmium
Chromium
Iron
Lead
Manganese
Mercury
Nickel
Selenium
Silver
Copper
Molybdenum
Zinc

Total Organic Halogen
Chemical Oxygen Demand
Total Organic Carbon

The ground water at a fly ash disposal site is monitored before and during the disposal operation to insure that the site is suitable for fly ash disposal, to provide for early detection of potential ground water pollution, and to insure that ground water pollution does not occur. The background water quality monitoring submitted with the permit application must include up and down gradient monitoring points with a minimum of six samples analyzed at monthly intervals for each point. All six samples are analyzed for mine drainage parameters (table 3), and at least one of the six samples must include analysis of the additional parameters (table 4). Fly ash disposal is not permitted at sites with polluted ground water, unless disposal would have a positive affect on water quality. This could apply on abandoned sites, where backfilling with fly ash could reduce surface water contributions to underlaying acid producing deep mine discharges.

Table 3.--Listing of basic mine drainage parameters required for ground water monitoring.

pH
Specific Conductance
Alkalinity
Acidity
Iron
Manganese
Aluminum
Sulfate
Suspended Solids
Total Dissolved Solids

Table 4.--Listing of additional ground water quality parameters required for ground water monitoring.

Arsenic
Barium
Cadmium
Chromium
Fluoride
Lead
Mercury
Nitrate Nitrogen
Selenium
Silver
Calcium
Magnesium
Chloride
Phenol
Sodium
Ammonical Nitrogen
Potassium
Copper
Zinc

The operational plan for the disposal site must be designed to minimize the potential for environmental degradation. Upslope runoff must be diverted away from the disposal area and site runoff must be controlled and treated, where necessary. The disposal area must be a minimum of 8 ft away from the permanent ground water table, the pit floor, highwall, and low wall. A suitable fine grained renovating material, other than topsoil or subsoil, is to be reserved or stockpiled for the area beneath the waste material, to attenuate any leachate that is formed. This material shall be a minimum of 8 ft in thickness.

The fly ash must be compacted to 90% of the Modified Proctor Test density to reduce the leaching potential at the site. The permeability of compacted fly ash has been shown to range from very low (10^{-7}cm/sec.) to low (10^{-4}cm/sec.) (G.A.I. Consultants, 1986). Fly ash is very easy to compact when the moisture content is maintained within 3-4% of the optimum (typically 17-20%). To minimize dusting during hauling and placement, the ash is typically conditioned at the plant with the addition of water. Simple testing will allow the optimum moisture content range to be achieved in the ash conditioning process. At the mine site the ash is required to be placed in lifts of 2 ft maximum and compacted with a vibratory or rubber-tired roller. Haulage equipment can often be utilized to obtain the desired compaction.

The ash solids analysis, leachate analysis, background water quality information, and operational plan are reviewed before a final decision is made on an application. On approvable sites the mining permit is revised to include fly ash disposal.

BENEFICIAL USE OF FLY ASH

The physical and chemical properties of coal ashes are dependent on the coal's geological origin, combustion conditions, efficiency of particulate removal, and degree of weathering before disposal or usage. Coal residues, applied on cropland, are not practical sources of essential plant nutrients: nitrogen, phosphorus, and potassium; however they can effectively serve as a supplementary supply for plant nutrients such as calcium, sulfur, boron, and molybdenum. Fly ash can also be an effective amendment in neutralizing soil acidity (Adriano, et al. 1980). The alkalinity of a fly ash is related to the sulfur content of the raw coal. The pH of coal ashes has been shown to range from a low of 4.5 to as high as 12.0 (Plank and Marsten, 1974).

Alkaline fly ashes have high calcium carbonate equivalency. This alkalinity and small particle size make these ashes attractive for use as a liming substitute or for improving the physical properties of soil at sites with acidic coarse textured soil. Other potential benefits of utilizing fly ash in reclamation include - providing fines for seedbed improvement and to increase plant available moisture retention, improving the soil bulk density, and providing plant micronutrients. These uses are appropriate on coal refuse reprocessing or remining sites, where sufficient topsoil material is not available.

The accumulation of boron, molybdenum, selenium and soluble salts in fly ash amended soils appear to be the most serious constraints associated with land application of fly ash to soil. Boron, Mo, and Se from the fly ash are readily accumulated in the plant tissue in significant quantities. High boron and soluble salts concentrations in the soil can be toxic to growing plants, whereas high Mo and Se uptake by plants are potentially hazardous to foraging animals.

Total boron concentrations in fly ash range from 48-618 ppm (Baker and Chesnin, 1975). Soils normally contain 4 to 88 ppm total boron (Capp, 1978). The saturation extract procedure (Bingham, 1982) has been found to be the best indicator for potential boron toxicity (Keren and Bingham, 1985). Saturation extract concentrations of boron in solution above 1 ppm are toxic to sensitive species. Boron as measured by the hot water soluble test is considered toxic above 20 ppm.

High fly ash applications to soils can increase molybdenum levels in forage crops to levels potentially toxic to animals feeding on the forage. Higher soil pH can increase the availability of soil molybdenum (Doran and Martens, 1972). Molybdenum concentrations ranging from 5 to 20 ppm are potentially hazardous (Alloway, 1968). The oxalic acid extractable test procedure is used to determine molybdenum soil concentrations (Reisnauer, 1965). Plant uptake analysis testing of Mo, Cu, and other potentially toxic metals should be undertaken before allowing extensive grazing.

Total selenium concentrations in the soil mixture ranging over 4 ppm are potentially hazardous, particularly to close grazing animals (Alloway, 1968). However because plants can accumulate toxic levels at soil levels below 4 ppm, it is advisable to test crops before feeding to livestock.

Unweathered fly ash can contain appreciable soluble salts that can be phytotoxic. Soluble salts levels are measured by electrical conductivity, however there are different ways of preparing the soil prior to the test. One method, which is utilized by Pennsylvania State University, performs the test on a 2:1, water:soil, extract. Ash/soil mixtures measuring more than 1.5 mmho/cm, with this test procedure, are not considered suitable for the establishment of most species adapted to soils of Pennsylvania. The electrical conductivity of fly ashes, measured with the water:soil extract procedure, ranged from 1.5 to 2.3 mmho/cm. Coal mine refuse generally ranges from about 0.5 to > 3.0 mmho/cm, while surface mine spoils range from 0.2 to about 2.0 mmho/cm (Capp, 1978). The result of mixing soil and fly ashes with differing soluble salts levels is generally positive, although it can not be predicted from the individual components. Recent literature (Rhodes, 1982) indicates that the saturation extract procedure, where water is added to form a paste, is a better indicator for soil/fly ash mixtures containing gypsum. Soluble salts, as measured by electrical conductivity of a saturation extract of the soil, should be maintained at a level below 4 mmho/cm, unless documentation is provided that species are tolerant at higher levels.

A proposal for beneficial use is submitted to the Bureau's District Mining Office for approval. It must include a justification for use; a description and location of the proposed activity; application rates; consent from property owners; a complete chemical and leachate analysis of the ash (tables 1 and 2); information on the existing soil or on site material; a description of the method of mixing, blending, and incorporating of the fly ash; and an analysis for pH and fertilizer requirements of the soil/fly ash mixture.

This information is needed to assess the potential environmental consequences of the surface application of the fly ash. Potential problems that must be given adequate consideration include pollution of surface or ground water, and toxicity to plants and grazing animals.

Soil tests of the existing soil are necessary to determine plant nutrient levels. This test is part of the normal mining application procedure and will help document the justification for fly ash utilization. As part of this test, the calcium carbonate equivalency of the ash should be determined. When a fly ash with low calcium carbonate equivalency is applied to acidic soils, the addition of agricultural limestone is necessary.

Various laboratory test procedures are undertaken to determine proper application and mixing rates. To insure an optimum plant growth environment and to reduce the potential for mobilization of heavy metals, the pH of the soil/fly ash mixture should be maintained between 6.5 and 7.0 (Baker and Amacher, 1981). As the ash will react chemically with the soil, the proper ratio of fly ash to soil is determined by mixing different amounts of the two constituents and measuring the resulting pH. To insure that chemical equilibrium of the two constituents has been reached, the sample is subjected to at least two wetting and drying cycles before the pH is determined (Buck and Houston, 1986). Other ash constituents such as metals can also cause problems. A Baker Soil Test for Mn, Fe, Cu, Zn, Na, Al, Pb, Ni, and Cd and a total sorbed metals test for Cu, Zn, Pb, Ni, Cd, and Cr should be performed on the fly ash/soil mixture (Baker and Amacher, 1981). The Baker Soil Test is a measure of metals and other constituents that are available to the plants. The sorbed test measures what is potentially soluble in the soil. The solids analysis required in Module 25 is a digestive procedure that measures the total amount contained in the ash.

Due to plant toxicity and food chain uptake concerns, the soil/fly ash mixture tested as described in the text shall fall within the following limits.

Boron	<	20 ppm
Molybdenum	<	5 ppm
Selenium	<	4 ppm

Safe levels of metals loading have been determined for land reclamation sites where sewage sludge is utilized (Baker, et al. 1984). These loading restrictions have been adapted for fly ash beneficial use sites. The following are Pennsylvania's standards for maximum lifetime heavy metals loading rates for nonagricultural land reclamation sites.

Cadmium	3	lb/acre
Copper	100	lb/acre
Chromium	100	lb/acre
Lead	100	lb/acre
Mercury	0.5	lb/acre
Nickel	20	lb/acre
Zinc	200	lb/acre

The metals loading rates for agricultural purposes are lower than those for land reclamation. The following are typical background soil constituent levels. Comparison of the composition of the ash with the composition of the soil to be amended is another useful check in determining proper mixing rates.

Table 5.--Typical levels of the constituents of background soil (ppm)*.

	usual range	typical
Aluminum	5,000-32,000	-
Arsenic	1-50	5
Barium	100-3,000	500
Boron	2-100	10
Cadmiun	0.01-0.7	0.5
Chromium	5-1,000	200
Iron	14,000-40,000	-
Lead	2-2,000	10
Manganese	200-3,000	850
Mercury	0.03-0.3	0.03
Nickel	5-500	40
Selenium	0.01-2.0	0.01
Copper	2-100	20
Molybdenum	0.2-5	2
Zinc	110-300	50
Sulfur	100-1500	850
Calcium	0.7-50	-

*adapted from Baker and Chesnin, 1975.

The Bureau of Waste Management has formulated an Interim Policy for Beneficial Use of Residual Waste. The following is an excerpt of the sections that apply to the use of coal ash as a soil substitute or soil additive.

INTERIM POLICY FOR THE BENEFICIAL USE OF RESIDUAL WASTE

PURPOSE

This policy was developed to address requests for exemptions from the residual waste permit requirements through a beneficial use determination by the Bureau of Waste Management. This policy also implements Act 168 of 1986, relating to the beneficial use of coal ash.

This policy will remain in effect until the Bureau promulgates its new residual waste regulations, scheduled for mid-1988.

SCOPE

(a) This policy sets forth beneficial uses of residual waste, including coal ash, and describes all notice requirements, design and operating standards, and siting criteria that are applicable to such beneficial uses.

(b) This policy applies only to those constituents of residual waste that are used or proposed to be used for a particular beneficial purpose in lieu of a marketable product, including a raw material or a finished product. This policy does not apply to residual waste landfills, residual waste disposal impoundments, the land application of residual waste, or any process that requires a residual waste processing permit under the Solid Waste Management Act.

(c) No beneficial use of residual waste shall be required to obtain a permit from the Department under the Solid Waste Management Act if such use complies with the provisions of this policy. However, any beneficial use of coal ash at a solid waste management facility for the disposal of solid waste, including coal ash, shall be subject to the requirements of the Solid Waste Management Act and regulations (e.g., coal ash as a cover supplement at a municipal waste landfill).

(d) All beneficial uses of residual waste described in this policy shall be subject to any applicable provisions of the environmental protection acts.

DEFINITIONS

The following words and phrases when used in this policy shall have the following meanings unless the context clearly indicates otherwise:

Beneficial use - Use, reuse, or reclamation of a material for commercial, industrial, or governmental purposes.

Coal ash - Fly ash, bottom ash, or boiler slag resulting from the combustion of coal.

Soil additive or soil substitute - The land application of coal ash, at specified loading or application rates, to replace soil that was previously available at the site or to enhance soil properties. The term does not include structural fills, valley fills, the use of coal ash to fill open pits from coal or noncoal mining, or the disposal of coal ash.

Structural fill - The engineered use of coal ash as a base or foundation for a construction activity that is completed promptly after the placement of the coal ash. The term does not include valley fills, the use of coal ash to fill open pits from coal or noncoal mining, or the disposal of coal ash.

Water source - The site or location of a well, spring, or water supply stream intake that is used for human consumption.

Wetland - Those areas which are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include, but are not limited to: swamps, marshes, bogs and similar areas. The term includes but is not limited to wetland areas listed in the State Water Plan, the United States Forest Service Wetlands Inventory of Pennsylvania, the Pennsylvania Coastal Zone Management Plan, and any wetland area designated by a river basin commission.

POLICY AND PROCEDURE

Section. Use of coal ash as a soil substitute or soil additive.

(a) Coal ash may be beneficially used as a soil substitute or soil additive without a permit from the Department under the Solid Waste Management Act if the person or municipality proposing such use complies with the provisions of this section.

(b) This section applies to any person or municipality that uses or proposes to use coal ash as a soil substitute or soil additive, whether or not such use of coal ash is part of an operation that requires a permit from the Department under the Surface Mining Conservation and Reclamation Act, 52 P.S. Sections 1396.1-.31, the Coal Refuse Disposal Control Act, 52 P.S. Sections 30.51-.66, or the Noncoal Surface Mining Conservation and Reclamation Act, 52 P.S. Sections 3301-3326.

(c) At least 60 days before the proposed use of coal ash as a soil amendment, the person proposing such use shall submit a written notice to the Department. The notice shall contain at a minimum:

(1) A description of the nature, purpose, and location of the project, including a topographic map showing the project area, including any wells, springs, streams, and wetlands within 1/4 mile and any soils maps of the project area. The description shall include an explanation of how coal ash will be stored prior to use, how the soil will be prepared for the application of the coal ash, how coal ash will be spread and, how ash will be incorporated into the soil.

(2) The estimated beginning and ending dates for the project.

(3) An estimate of the volume of ash to be used for the project, and the proposed application rate.

(4) A chemical and leaching analysis for the ash to be used in the project. If the coal ash was generated at a facility for which the Department has previously approved a chemical and leaching analysis, the person may submit a copy of the analysis that was approved.

(5) A chemical analysis of the soil on which the ash is to be placed.

(6) An analysis showing how the application will be beneficial to the productivity or properties of the soil to which it is to be applied. The analysis shall be prepared and signed by an expert in soil science or agronomy.

(7) A signed statement by the owner of the land on which the coal ash is to be placed, acknowledging and consenting to the use of fly ash as a soil amendment.

(d) Coal ash used as a soil substitute or soil additive shall not be considered a beneficial use unless all of the following requirements are met:

(e) After receiving the information required by subsection (c), the Department may inform the person or municipality that provided the information whether the proposed usage is consistent with the requirements of this section.

(1) The person or municipality has provided to the Department the information required by subsection (c) at least 60 days before using coal ash as a soil substitute or soil additive.

(2) The pH of the coal ash and the pH of the soil shall each be in the range of 6.5 to 8.0 when mixed together in the manner required by the project, as shown by field and laboratory testing. Lime addition may be used to raise pH.

(3) No slope on which coal ash has been placed shall exceed 15%, except that the Department may allow slopes of up to 20% in writing.

(4) Surface runoff from the project area shall be controlled during the project. Collection of surface runoff shall be controlled in accordance with The Clean Streams Law and the regulations promulgated pursuant thereto.

(5) Surface water shall be diverted away from the disturbed area of the project.

(6) The person or municipality conducting the activity shall have a Department approved erosion and sedimentation control plan in accordance with Chapter 102 (relating to erosion and sedimentation control.

(7) Coal ash shall not be placed within 4 feet of the seasonal high water table.

(8) Coal ash shall not be placed within 8 feet of the permanent ground water table.

(9) Coal ash shall not be used so as to cause ground water pollution, contamination, or degradation.

(10) Coal ash shall be incorporated into the soil within 48 hours of application.

(11) Coal ash shall be applied at a rate per acre that will protect public health, public safety, and the environment.

(12) Coal ash shall not be applied to any soil currently being used for agriculture where the soil pH is less than 5.5.

(13) Coal ash shall not be applied if resultant chemicals or physical soil conditions would be detrimental or toxic to biota.

(f) Except as provided in subsection (g), coal ash may not be used as a soil substitute or soil additive:

(1) Within 100 feet of any intermittent or perennial stream.

(2) Within 300 feet of any ground water source.

(3) Within 500 feet upgradient of any surface drinking water source.

(4) Within 100 feet of any sinkhole or area draining into a sinkhole.

(5) Within 300 feet measured horizontally from any occupied dwelling, unless the current owner thereof has provided a written waiver consenting to such activities closer than 300 feet. The waiver shall be knowingly made and separate from a lease or deed unless the lease or deed contains an explicit waiver from the current owner.

(6) Within 300 feet of any important wetland, except as provided in 25 Pa. Code Section 105.7 (relating to important wetlands).

(g) If the applicant can affirmatively demonstrate to the Department that the coal ash does not contribute to environmental degradation comparative to the background soil, the Department may modify the isolation distances set forth in subsection (f).

Departmental approval for the beneficial use of fly ash on active mine sites is considered as a permit revision. As such the existing permit is amended to include ash utilization conditions.

CASE STUDIES

The two case studies which follow illustrate the successful use of fly ash as a soil amendment in revegetating active coal waste mining sites..

Harwood Coal Waste Site

The 10-acre Harwood Site, located near the city of Hazleton in northeastern Pennsylvania, was used as an anthracite refuse storage area for an abandoned coal-fired generating station owned by Pennsylvania Power and Light Company (P.P. & L.). The coal fines were removed by P.P. & L. in 1984. As required by Departmental regulations, P.P. & L. was responsible for reclamation of the site.

To determine the feasibility for beneficial use at this and other sites and to reduce reclamation costs, P.P. & L. decided to utilize fly ash from their Montour County bituminous fired generating station as a soil amendment. The remaining on-site waste material had a typical pH of 4.0, high coarse fragment content, and poor moisture retention. The ash from the Montour generating station had a pH of 6.0, excellent fine fragment content, and when combined with on site material would provide excellent moisture retention. The soluble salts level of the ash was very high in some samples (1.5-2.0 mmhos/cm. in a 2:1 water/soil extract), and boron, molybdenum and selenium levels were also very high (18.2, 35.4, and 6.4 ppm, respectively) (Buck, 1988).

Mixtures of fly ash and coal waste were made in the laboratory to determine the near equilibrium chemistry of the mixture. From these tests, an application rate of 230 tons/acre (17% moisture) was determined. The 230 tons/acre corresponds to a 2-inch thick applied depth of fly ash over the entire site. With this application rate and incorporation to a 10-inch plow depth, the soluble salts, molybdenum, selenium and boron concentrations were kept to within allowable Departmental standards.

Incorporation was achieved with a chisel plow during August 1984. Success of the vegetation has been excellent to date. Monitoring of the surface ground water at the site, which is being studied until June 1988, has not shown any negative affects of the ash usage. The pH of the surface water has increased from a pH of 3.4 before reclamation to nearly neutral values. Since metal solubility is reduced at neutral pH's, concentrations of aluminum, copper, iron, manganese, and zinc in the surface water runoff from the site have decreased significantly.

Brook Contracting Coal Waste Site

Another coal refuse reprocessing site where fly ash has been utilized in reclamation is the Brook Contracting site, located in the boroughs of Summit Hill and Lansford, Schuylkill County, Pennsylvania. The existing refuse material had a pH of 4.6. Laboratory tests determined that a 100 tons/acre application rate of P. P. & L. Montour Station fly ash, combined with an application of 2 tons/acre of agricultural limestone would yield a soil pH of 6.5. The ash and limestone was applied, incorporated, mulched, and seeded in April 1987. Revegetation success has been good. With the exception of manganese (6.15 mg/l), analysis of runoff samples has shown metal loadings to be below acceptable drinking water standards. The high manganese concentrations in the coal waste, not the fly ash application, was likely responsible for the elevated concentrations.

SUMMARY AND CONCLUSION

While the percentage of fly ash and bottom ash utilized for commercial or construction purposes has increased significantly, the amount that still must be disposed of is in the range of 6 million tons annually in Pennsylvania alone. The Pennsylvania Department of Environmental Resources has revised its coal activities permitting procedures to allow for a timely review of applications to dispose of fly ash on mine sites or utilize fly ash in reclamation activities. While not all mining sites or fly ashes are suitable for these activities, the new procedures are useful in identifying environmentally acceptable disposal sites and beneficial use sites.

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RECLAMATION PLANNING AND ITS EFFECT ON BOND RELEASES

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The land which we mine is located in a poverty stricken section of southeastern Ohio. Back when our economy was set up so that a small farmer could make a decent living at farming, this land was farmed quite heavily where the slopes flattened out enough to allow crops to be raised. The steeper areas were used for pasture and, as a result, trees would grow in these areas, since they were too steep to be farmed. As our economy changed, the small farmer could no longer keep farming and the land was let go with little or no management and the result was some very poor undeveloped land, a lot of which has been previously mined and unreclaimed.

The land use, which the majority of our mined area is put to, is that of grazingland. This use includes both grassland and forestland where the indigenous vegetation is actively managed for grazing, browsing, or occasional hay production. This has worked out well for us, and the landowner is well pleased with the results.

All of our mining is done by surface mining methods. When possible, each is placed in the hole made by the previous cut except for excess spoil, which might have to be placed in areas outside the mined out area or blended into the surrounding contour to compliment and provide positive drainage.

Most of the land which we mine has no topsoil as such. The steeper areas generally are covered with rock outcroppings, or they have been previously mined and unreclaimed, and therefore, there is very little recoverable soil. However, in most of the flatter areas, the subsoil is of appreciable thickness to provide enough material to more than adequately cover the entire mined area after being regraded. When possible, the regrading is done as mining progresses, and the resoiling material is replaced as soon as weather permits.

As soon as we put down the resoiling material we start preparing the seedbed by discing, fertilizing and liming, according to soil test recommendations, then we disc again prior to seeding. The seed, which we use, is a mixture of grasses and legumes which includes Kentucky 31 forager fescue, orchard grass, timothy, red clover, ladino clover, alsike clover, and alfalfa or birdsfoot trefoil. After the seed has been distributed, the mulching is done at the rate of three tones per acre with a large round bale mulcher. As quick as the mulch is placed, it is crimped along the contour, to hold it in place and to minimize erosion.

We only prepare enough ground, which we can get totally completed through crimping, in a days time or prior to a rain. We always start at the highest elevation and work toward a lower elevation so that, if a rain occurs, the areas that has been completed will be adequately protected and there will be very little redo work.

After the reclamation phase, we continually monitor the area to see if there is any erosion taking place, especially after a rainfall. If there are any places which need some repair, then it is taken care of before there is a bigger problem.

The thing which has really done the most for us, has been the proper design, construction and maintenance of our drainage control systems. This includes, the sediment ponds, the diversion ditches, the rock channels, the proper contouring of the ground throughout regrading and resoiling, and the proper mulching and crimping techniques. As a result, we don't have any trouble getting our partial bond releases, and although we have not gotten to the end of any of our five year maintenance periods, we don't feel, nor does the regulatory authority feel that we will have any trouble getting our final bond releases. We always get our partial releases, just as soon as possible. We want the five year maintenance period to start as soon as it can. We constantly communicate with the inspectors to assure that everything is being done which they feel necessary, so that we can get timely bond releases.

As a result of our planning, construction, maintenance, and communication with the regulatory authority, we not only get timely bond releases, we also eliminate the violations which would result if we hadn't done these things. We feel that, according to law, we have to do these things eventually anyway, so why not do them harmoniously and timely, and, at the same time, save us some money when the final, total costs of the mine are tallied.

SUCCESSFUL BOND RELEASE PRACTICES IN NORTH DAKOTA

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The North Dakota Public Service Commission (PSC) has approved 16 partial bond releases for backfilling and grading and suitable plant growth material (SPGM) replacement on about 2,400 acres mined after the effective date of the permanent regulations pursuant to SMCRA. Only one partial bond release for vegetation establishment has been approved. The North Dakota state program includes a four-stage bond release process. Up to 40 percent of the bond can be released for backfilling and grading, another 20 percent for respreading of topsoil and subsoil, and the remainder, except revegetation costs, for vegetation establishment. The final amount is not released until productivity standards have been achieved and the ten-year liability period has expired. Partial bond releases for the first three stages have been approved by PSC on 234.9 acres at The North American Coal Corporation's Indian Head Mine near Zap, North Dakota. One final bond release has been approved for a recreational land use at the Falkirk Mine, near Underwood.

Coal mining in North Dakota is done mostly at large surface mines where draglines, bulldozers, and tractor scrapers are used for mining, backfilling, grading, and topsoil and subsoil handling. Land use is primarily agricultural. Cropland is used for small grain and hay production. Substantial acreages are also reclaimed to native grassland and wildlife habitat.

A regrade approval application must be approved prior to any respreading of soil. Approval of respread subsoil is required before topsoil can be respread. First stage bond release is a straightforward numerical evaluation based on reclaimed topography data submitted in the application and a field inspection. Second stage bond release consists of a field inspection during which respread soil is sampled to ensure average respread thicknesses corresoond to those approved in the regrade application. There are, of course, prodigious public and government agency notice requirements and opportunities for participation by the public and various officials in these bond release activities. Monitoring of reclamation operations by the PSC and reclamation quality control by the operator generally result in a time-consuming, but routine bond release application and approval process for the first two stages.

Approval of bond release for vegetation establishment on cropland is based on a PSC field inspection. Adequate establishment of the precropland mix or "crop to be grown" is evaluated and the area is inspected for erosion potential. Third stage bond release on native grassland will require quantitative measurements of cover, as well. Proof of equal or greater productivity must be provided for third stage bond release on prime farmland. No applications for third stage bond release have yet been submitted for native grassland or prime farmland.

One final bond release, for 165 acres of recreational land which is being developed as a golf course, has been approved at the Falkirk Mine. Falkirk was required to prove adequate cover through sampling, and field inspections were conducted. No final bond release applications have yet been submitted on cropland because of the ten-year liability period. However, preliminary yields from hay cut on the areas are encouraging. Requirements for seasonality, permanence, and diversity on native grassland may make final bond release on that land use more difficult.

Participation in bond release inspections by landowners, the PSC's technical review committee, and others has gone well. Participants, especially landowners, often question the ten-year liability period requirement. Landowners are anxious to recover full control of their land, once they are convinced that is fully reclaimed.

A bond release application is a significant administrative effort. Legal descriptions must be developed, updated lists of area and adjacent landowners must be compiled for notifications, notices must be published, and data must be compiled and analyzed regarding the reclaimed site itself. Questions and concerns raised by surface and coal owners and numerous regulatory agencies must be addressed. Several inspections are often required because it may be difficult to schedule all interested parties on the same day. Nevertheless, bond release is worth the effort because of its significance as an official measure of reclamation success.

PARTIAL RECLAMATION BOND RELEASE IN WYOMING

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In January 1988, partial reclamation bond release was approved for some 935 acres of permanently reclaimed land at Kerr-McGee's Jacobs Ranch Mine in the Powder River Basin of Wyoming. This represents the largest area in Wyoming, if not the entire West, where reclaimed land has received partial bond release and has been returned to its premine grazing use. This approval by the Wyoming Department of Environmental Quality-Land Division (WDEQ-LQD) with the concurrence of the Office of Surface Mining Reclamation and Enforcement (OSMRE) and the United States Forest Service (USFS) reflects the success of the mine's reclamation program. The success has been demonstrated by annual studies which show that the reclaimed areas are more productive than the surrounding native rangeland and by the successful return of cattle grazing to these areas for four consecutive years. In fact, these reclaimed areas meet the regulatory criteria for final bond release except for completion of the mandatory ten year bonding period.

The Jacobs Ranch Mine is a surface coal mining operation of Kerr-McGee Coal Corporation located approximately 52 miles southeast of Gillette, Wyoming. The mine is a two-pit, truck-shovel operation, mining coal from three seams varying in thickness from thirty to seventy feet. The permit area encompasses approximately 5,000 acres of which some 1,200 acres have been permanently reclaimed. Prior to mining, the land use was rangeland and incidental wildlife habitat. Livestock grazing has continued on inactive portions of the mine site. After mining, the area will return to ranching with improved rangeland and improved water wells and stockpiles.

Up to five feet of topsoil and subsoil is removed with scrapers prior to overburden removal. The overburden is removed in forty-foot benches and trucked to the backfill areas where it is placed on the backfill lifts in the same sequence in which it was taken (i.e., top material to the top, and bottom material to the bottom). Any significant quantities of unsuitable backfill are placed on the lower backfill lifts. The Mine Plan provides for analysis of composite samples from the upper four feet of the top backfill lift to verify that no unsuitable materials are present prior to placing thirty inches of topsoil.

Once the topsoil is graded and ripped, the area is usually planted with a fast growing temporary cover such as oats to rapidly stabilize the area. This stubble mulch is usually less expensive and more effective than normal mulch for temporary erosion control. Permanent final revegetation is accomplished with a rangeland seed mix which includes eleven types of grasses and shrubs. Seed is applied at a rate of about eighteen pounds per acre, making an average in excess of 35 pure live seeds per square foot. After about three growing seasons, vegetation studies are conducted to determine whether grazing can be resumed and to define the grazing capacity of the area.

In response to Kerr-McGee's request for partial bond release, representatives of four state and federal agencies participated in the field inspection of the partial bond release area in the summer of 1987. Topsoil and subsoil depths in twenty-eight holes were measured. Soil texture and composition were analyzed over the area. A series of vegetation surveys and wildlife evaluations were also conducted by the agencies on the proposed bond release area. Positive results of their evaluations were the basis for approval of the partial bond release. Considering that the area presently meets the regulatory criteria for full bond release, it is anticipated that the final bond release will be approved at the expiration of the mandatory ten year bond holding period.

PURSUING EXPEDITIOUS RELEASE OF RECLAMATION BONDS HELD ON POST-MAY 3, 1978, AFFECTED AREAS

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AMAX Coal Company recognizes the benefits of pursuing expeditious release of reclamation bonds. With over twenty-eight thousand acres of current or potential reclamation liability at six surface mines in the Midwest alone, the importance of timely reclamation, achievement of performance standards and submittal of release requests cannot be overemphasized. In addition to the expense of bond premiums and limitations on bonding capacity, reclaimed areas where release is not expeditiously sought can require expensive remedial reclamation to repair and revegetate erosion before once again being eligible for release.

AMAX is currently pursuing bond release at two exhausted mine sites. Thirty-five hundred acres were affected under the Indiana and Illinois Interim Regulatory Programs and Illinois Permanent Program prior to mine closures in 1983 and 1984. The success of AMAX's active release program is briefly outlined below.

In summary, AMAX has been successful in achieving expeditious release of bonded areas through cooperation among and the diligent efforts of reclamation, revegetation, permitting and bonding personnel.

MINE NAME/LOCATION:	Wright Mine/southern Indiana
PRODUCTION YEARS:	1954 to 1983
TONS PRODUCED:	37 million (bituminous)
MINING TECHNIQUE:	Area surface mining
OVERBURDEN REMOVAL:	Marion 5761 (65-yard bucket), Marion 5561 (45-yard bucket) shovels; Marion 7400 (13-yard bucket) dragline
RECLAMATION EQUIPMENT:	Caterpillar and Terex tractors, Terex and WABCO scrapers
ACRES AFFECTED:	6,000 total; 1,300 under Surface Mining Control and Reclamation Act (SMCRA)
POSTMINING LAND USES:	Cropland (43%), pasture & hay (48%), water (9%), wildlife (1%)
REVEGETATION:	Aerial, ground and hand seed. Fescue, brome, alfalfa, alsike, wheat, autumn olive, bald cypress, dogwood, green ash, virginia pine, lespedeza, black locust
BOND RELEASE STANDARDS:	NOTE: All standards IN Interim Reg. Program Cropland: wheat, yield estimated Pasture & Hay: species diversity and % ground cover Wildlife: % survival
COMMENTS:	Last coal was loaded from active pit January, 1983. 962 acres still bonded March, 1985. Only 5-acre equipment compound still bonded as of December, 1987. Several downdrains blew out over winter of 1984-1985. Were replaced and concreted in place to ensure long-term performance. Key factors in expeditious bond release: reclamation manager kept on-site for one year past end of soil replacement, personnel involved and good weather. All land has been sold and new owner is establishing residential subdivision oriented around mining-created final cut and incline water impoundments.

MINE NAME/LOCATION: Sun Spot Mine/western Illinois

PRODUCTION YEARS: 1962 to 1984

TONS PRODUCED: 17.6 million (bituminous)

MINING TECHNIQUE: Area surface mining

OVERBURDEN REMOVAL: Marion 5761 shovel (65-yard bucket); Marion 8750 (110-yard bucket) and Marion 7800 (31-yard bucket) dragline

RECLAMATION EQUIPMENT: Caterpillar and Fiat-Allis tractors, Caterpillar scrapers

ACRES AFFECTED: 6,000 total; 2,250 under Surface Mining Control and Reclamation Act (SMCRA)

POSTMINING LAND USES: Cropland (39%), pasture & hay (29%), forestry(19%), wildlife habitat (6%), water (7%)

REVEGETATION: Depends on land use. Cropland is alfalfa, wheat and corn rotation. Pasture & Hay is alfalfa or clover. Forestry and wildlife habitat: various species.

BOND RELEASE STANDARDS:
Cropland: productivity, 2 crops-one corn (both Interim & Permanent Program)
Pasture & Hay: % ground cover (Interim Program)
productivity, hay tons/acre (Permanent Program)
Forestry: survival (450 live stems/acre)
Wildlife: survival

COMMENTS: Last coal was loaded from active pit in 1984. 3,300 acres still bonded December, 1987. 1,300 acres were reclaimed to Illinois Rule 1104/High Capability Land Standards (48" topsoil and suitable rooting medium replaced) and 16.5 acres were reclaimed to Prime Farmland Standards (same soil replacement as above; 100% premining productivity required). While most cropland areas will remain bonded for several years while crops are grown in an attempt to achieve the productivity required for release, AMAX successfully proved cropland productivity on 11.3 acres of reclaimed Rule 1104 land mined in 1982. In 1984 AMAX achieved 64 bushel/acre wheat when the target yield was 44.4. In 1986 AMAX achieved a corn yield of 152 bushels/acre when the target yield was 129 bushels acre.

Most Interim Program non-cropland is released. Fall, 1988, is first season Permanent Program areas are eligible for release. Significant forestry and wildlife habitat releases are anticipated.

SOIL SALVAGE REQUIREMENTS BASED ON OVERBURDEN QUALITY - APPLYING THE RESEARCH[1]

Michael W. Pole[2]

Abstract. -- North Dakota State regulations governing the reclamation of surface mined lands have recently been changed as a result of cooperative efforts by the regulatory agency, the research community, and the regulated industry. Since 1975, operators had been required to salvage and respread all available suitable plant growth material, up to 5 ft thick, over regraded overburden because overburden materials in some areas were not suitable for plant growth. However, in the many areas of the state where regraded overburden is suitable for plant growth, presumably less soil needs to be respread. Research directed toward determining respread soil thickness requirements culminated in 1986 in an effort to change soil salvage and respread regulations through the administrative process established by the Surface Mining Control and Reclamation Act of 1977 (SMCRA) and the North Dakota State program. The rule-making process was difficult, time-consuming, and frustrating, but the resulting regulatory changes should improve both the quality and cost-effectiveness of reclamation operations in North Dakota. Factors which contributed to this successful application of research results to regulatory changes in North Dakota include participation by independent research organizations, long-term financial support for reclamation research, frequent and effective communications among technical staffs, and active participation by all parties in the rule-making process.

INTRODUCTION

Regulatory agencies, coal mining companies, and environmental organizations have all argued that laws and regulations affecting coal mining and reclamation operations should be based on the best available scientific research. Both State and Federal reclamation laws include provisions which encourage reclamation research. Since the enactment of The Surface Mining Control and Reclamation Act of 1977 (SMCRA), numerous reclamation research experiments have been completed. This research has resulted in a tremendous increase in our knowledge of the science and technology of reclamation. Application of improved reclamation techniques, based on more than 10 years of research since the enactment of SMCRA, should improve the quality and the cost-effectiveness of reclamation. However, the application of these research results is often impeded by the considerable efforts required to change State and Federal laws, regulations, and guidelines. Regulatory agencies, the mining industry, and environmental organizations are understandably hesitant to change an environmental design or performance standard which may be imperfect but is acceptable to all three groups and has survived the arduous tests of the courts. Nevertheless, innovation is inextricably related to change, and innovation is absolutely necessary to ensure that reclamation is as successful and as economical as possible. Despite the obstacles, research results can be used to improve reclamation, even if regulatory changes are necessary, as evidenced by the recent changes to soil salvaging regulations in North Dakota.

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[1] Paper presented at the 1988 Mine Drainage and Surface Mine Reclamation Conference sponsored by the American Society for Surface Mining and Reclamation and the U. S. Department of the Interior (Bureau of Mines and Office of Surface Mining Reclamation Enforcement), April 17-22, 1988, Pittsburgh, PA.

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The lignite coal mining region of North Dakota includes many areas which are blessed with an abundance of topsoil and subsoil, referred to as suitable plant growth material (SPGM) in the North Dakota regulations governing the reclamation of surface-mined lands. In some areas, however, SPGM is quite limited. Similarly, the quality of the regraded overburden near the reclaimed surface is quite variable. Regraded overburden in some areas is virtually identical to subsoil and is an excellent substitute for subsoil. However, in other areas regraded overburden is high in sodium and other salts or has a coarse texture limiting its plant-available water-holding capacity. North Dakota's reclamation regulations were initially developed on the basis of the "worst case scenario", that is, the assumption that the overburden placed in the reclaimed plant root zone would be deleterious to plant growth and that all available SPGM should, therefore, be salvaged and respread to bury the overburden below the plant root zone.

SOIL HANDLING REGULATIONS IN NORTH DAKOTA

North Dakota's first reclamation law was passed in 1969, but it wasn't until the law was amended in 1973 that operators were required to salvage and respread topsoil up to 2 ft thick, where available. In 1973 and 1974 USDA Agricultural Research Service (ARS) scientists at the Northern Great Plains Research Center in Mandan, ND, began to warn that high sodium levels in regraded overburden might frustrate attempts to reclaim mined lands (Power et al. 1974, Sandoval et al. 1973). A 1975 ARS progress report identified the apparent phenomenon of upward sodium migration from the regraded spoil into the respread SPGM (Agricultural Research Service 1975). Consequently, the 1975 amendments to the North Dakota law provided for salvaging of up to 5 ft of SPGM. In 1976 North Dakota State University scientists suggested that 2.5 ft of SPGM was insufficient when underlying spoil materials have high concentrations of sodium and more than 35 percent clay (Bauer et al. 1976). By 1977 scientists were recommending that up to 3 ft or more of SPGM should be salvaged, but that further research was needed to determine soil thickness requirements (Reis et al. 1977, Agricultural Research Service 1977). The 1977 amendments to the North Dakota law required that all inventoried SPGM should be salvaged, which effectively restated the requirement to salvage 5 ft of material, if available.

In 1977 the requirement to salvage up to 5 ft of SPGM for replacement over sodic spoils was hard to dispute, considering the unknowns regarding potential sodium migration from sodic spoils. However, in many areas regraded overburden is neither sodic nor otherwise deleterious to plant growth, and presumably less SPGM is needed in those areas. In February 1977 The Falkirk Mining Company submitted a request to the North Dakota Public Service Commission (PSC) for a variance from the requirement to salvage subsoil on 190 acres at the Falkirk Mine. To support its request, Falkirk provided analytical data from an intensive drilling program which indicated that concentrations of sodium and other salts in the overburden would not be detrimental to plant growth. The state regulatory agency, the North Dakota Public Service Commission (PSC), denied the variance request in April of that year. The PSC did not disagree with Falkirk's contention that chemical characteristics of the overburden were good. However, it was concerned that the texture of some of the overburden was too coarse to be placed within the reclaimed plant root zone. According to a PSC letter of April 5, 1977, it was feared that such coarse material, "...when placed near the surface after backfilling and reshaping, could present a problem of excessive subsoil drainage and a droughty rebuilt soil profile." Nevertheless, the PSC stated that it would consider modifying its position if Falkirk would provide additional data supporting the variance. The PSC suggested regraded overburden sampling and soil moisture retention studies to obtain such data.

SOIL RECLAMATION RESEARCH

The PSC consulted with the ARS staff at the Northern Great Plains Research Center and the Soils Department of North Dakota State University before responding to Falkirk's request. The ARS had begun investigating soil respread thickness requirements at several surface mining sites in western North Dakota. Its research, however, was aimed primarily at the problem of reclaiming areas where highly sodic spoils are common. The North Dakota State University Reclamation Research Group, now called the Land Reclamation Research Center (LRRC), is also located at the Northern Great Plains Research Center. The LRRC was, at that time, conducting ground water and soil water studies at the Falkirk Mine, where sodic spoils are very uncommon.

In 1978, through a research grant from Falkirk, the LRRC scientists were able to expand their studies to include evaluations of topsoil and subsoil requirements for reclamation, based on regraded overburden properties. The Falkirk Trench Plots, constructed in the fall of 1978 at the Falkirk Mine, were the last in a series of topsoil and subsoil treatment plots constructed at western North Dakota surface mines by the ARS and the LRRC. The lignite industry in North Dakota made substantial investments in this research, including constructing the plots to the researchers' specifications and providing some of the funding. Lignite industry environmental specialists believed that salvaging all suitable plant growth material up to 5 ft was unnecessary, and they knew that the potential cost savings would be substantial. As early as 1976, Falkirk estimated that reclamation costs could be decreased by approximately $2,400/acre if the salvage requirement could be reduced to 2 ft from 5 ft. For a mine that disturbs about 300 acres/year, that could mean an annual savings of $720,000, based on 1976 costs.

There have been a number of soil depth experiments at North Dakota coal mines, but three of them deserve special mention. These have been referred to as the Stanton Wedge, the Zap Double Wedge, both conceived and developed by the ARS, and the LRRC Falkirk Trench Experiments. The details regarding plot construction, data collection and analyses, and experimental results can be found in numerous publications written by the scientists conducting these experiments (Power et al. 1981, Merrill et al. 1982, Halvorson et al. 1986). The Stanton Wedge Plot consists of a wedge of subsoil 175 ft long, varying in depth from 0 to 7 ft, spread over sodic spoil (SAR about 28). Topsoil thickness treatments were 0, 8, and 24 inches. The Zap Double Wedge, 410 ft by 335 ft, consists of a double wedge of three different subsoil materials varying in thickness from 0 to about 42 inches thick. The Double Wedge Plots were covered overall with an average thickness of 10 inches of topsoil. The underlying spoil was sodic and marginally saline. The Falkirk Trench Plots were eight trenches backfilled with three different textures of spoil material. Various amounts of subsoil and topsoil were respread over each trench. Each trench is 191 ft long, 53 ft wide, and 15 ft deep. All of the spoil was nonsodic and nonsaline. The ARS and LRRC conceived and developed these projects independently. Except for partial funding for the Falkirk Trench Plots, both research organizations obtained funding from traditional sources, that is, designated State and Federal research funds. The lignite industry was consulted, and cooperated by providing land, constructing the plots, and providing expertise in reclamation operations. The PSC (the state regulatory agency) was consulted from conception through analyses of results for each project. It was this close coordination, on the technical level, that ultimately resulted in the successful technology transfer from the research community to the State regulations and, ultimately, to the mine sites themselves.

The successful application of this research did not occur without considerable difficulties, and perseverance and tenacity were required of the researchers and environmental scientists in both the lignite industry and the regulatory agency. The lignite industry's environmental staffs found it necessary to justify the lignite industry's investment in and support of this research, with no assurance that the research would result in any savings, although early research results were promising. The PSC was frequently pressured by the lignite industry to modify regulations to reduce reclamation costs and by other special-interest groups to do the opposite. The researchers, of course, had to justify their reluctance to base recommendations on insufficient research. This was especially true for the LRRC, which gradually took the lead in reclamation research in North Dakota, as the ARS reclamation research program was scaled down in the early 1980s.

REVISING RECLAMATION REQUIREMENTS

Finally, in 1982 Falkirk submitted a mining permit revision application to the PSC to request a reduction in the soil salvage requirements from 60 inches to 40 inches. The application included a four-page letter from the LRRC director supporting Falkirk's request. The revision was approved by the PSC in late 1982. Reclamation cost savings resulting from this revision in soil salvage thickness requirements were estimated to be approximately $4.3 million.

In 1984 the LRRC and ARS researchers published North Dakota State University Agricultural Experiment Station Bulletin 514 (Doll et al. 1984), summarizing the results of all soil replacement research conducted in North Dakota to that date and including respread thickness recommendations, in tabular form, based on regraded overburden characteristics. During 1985, lignite industry and regulatory agency environmental scientists worked together to develop new soil salvage regulations based on the recommendations included in Bulletin 514. Despite the intimate involvement of both groups in the conception and development of this research, there was considerable disagreement regarding the form and substance of new regulations. For example, Bulletin 514 includes ranges of required respread soil thicknesses, and research since 1984 suggests that even the reduced thicknesses in Bulletin 514 may be too conservative. As a result, the lignite industry and the regulatory agency disagreed on the interpretation of Bulletin 514. Both groups were also influenced by non-technical factors. For example, industry environmental specialists would have preferred generalized regulations adaptable to "site-specific" situations, rather than the "design standards" inherent in an abbreviated table of allowed respread thicknesses. However, a fixed set of numbers was written into the proposed regulations to minimize the uncertainty of site-specific interpretations. The regulatory agency environmental scientists, on the other hand, found themselves supporting an apparent relaxation of environmental protection standards, a very difficult position for them to defend.

As a result, two separate sets of proposed regulations were presented at the public hearing held in March of 1986 and, inevitably, one set was unofficially labeled as the Lignite Council proposal and one as the PSC staff proposal. Many interested North Dakotans were present for the hearing. All who testified were examined and cross-examined by three attorneys and their advisors, as well as the three elected Public Service Commissioners. The three attorneys represented the PSC staff, the North Dakota Lignite Council, and the Dakota Resources Council. Numerous persons testified, but the key witnesses were the three LRRC and ARS research scientists who wrote Bulletin 514. It was not an entirely pleasant experience for the research scientists, but their willingness to discuss and defend their work in that forum made it possible for the lignite industry and the PSC to finally apply more than 10 years of research to the "real world."

The resulting regulations, which were finally approved by the U. S. Office of Surface Mining (OSM) in late 1986, are not perfect in the technical sense, but they represent a very considerable leap forward in our efforts to use research results to improve reclamation and to reduce unnecessary reclamation costs. The gist of these regulations is shown in table 1. In most cases, reclamation costs will be reduced because less soil will have to be salvaged. Reclamation cost savings for each acre-foot of soil which does not have to be salvaged are more than $1,000. Associated costs for reclamation bonds, topsoil and subsoil stockpiles, and water management facilities to control runoff from those stockpiles will also be reduced.

Table 1. -- Suitable plant growth material redistribution thicknesses required by North Dakota State regulations.

Spoil Properties			Total Redistribution Thickness (topsoil plus subsoil)	
Texture	Sodium Adsorption Ratio (SAR)	Saturation % (SP)	Avg. in Inches	Avg. in Centimeters
Medium[1]	<12	NA[2]	24	61
Coarse[3]	<12	NA	36	91
NA	12-20	<95	36	91
NA	12-20	≥95	42	107
NA	>20	NA	48	122

[1] Loam or finer
[2] Not applicable
[3] Sandy loam or coarser

Of course, some reclamation-related costs may increase as a result of the new regulations. For example, unless the overburden were toxic, the amount of suitable plant growth material required for respread under pre-existing regulations was never more than the amount available for salvaging. However, under the new regulations, minimum respread thicknesses are specified, and, if the soil classifier identifies less than the minimum amount, substitute subsoil must be identified, salvaged, and respread. Also, administrative costs have increased substantially under the new regulations. When all suitable plant growth material was salvaged and respread, minimum respread thicknesses and variability in respread thickness were not serious concerns, since more than enough was being respread in most cases. With the new regulations, the mining company must ensure that sufficient soil is salvaged to provide for a minimum thickness of respread soil, taking into account compaction and variability of respread thicknesses. Regraded overburden sampling programs and improved soil inventory techniques are required to ensure that sufficient soil is respread and to avoid the costly salvaging of excess soil. Nevertheless, cost savings resulting from reduced subsoil salvaging requirements should much more than compensate for these additional costs.

RESULTS AND CONCLUSIONS

Years of research and hundreds of thousands of dollars have been expended to develop better and more cost-effective soil handling regulations in North Dakota. There are surely many other areas where regulations can, and should, be changed to improve reclamation and to decrease unnecessary reclamation costs. Following are several factors which contributed significantly to the successful application of soils research to changes in reclamation regulations in North Dakota.

1. The research was conducted by well established research organizations with widely respected reputations in the field of study. Both organizations (ARS and LRRC) operated independently of the regulatory agency, the lignite industry, or any other special-interest group. The reputations and independence of the LRRC and ARS added immeasurably to the prestige of arguments made to change the regulations.

2. The foresight of the State of North Dakota in being willing to fund reclamation research was a critical, positive factor in ensuring that this research was undertaken and completed. This commitment is necessary to ensure that it is worthwhile to initiate experiments to evaluate the long-term productivity of reclaimed agricultural lands.

3. The research organizations consulted with potential users (the lignite industry and the PSC) at every stage of the research process, through both regularly scheduled meetings and more informal communications. Inputs from industry and the PSC were used to improve the applicability of anticipated research results, but were used only at the researchers' discretion, so that the integrity of their experiments was not adversely affected. Communications among the parties were on the technical staff level, to minimize the influence of institutional constraints on the research. Because of these early and continuing communications with industry and the PSC, all three parties supported the basic objectives of the research, even though there were often disagreements as to how the resulting data should be interpreted.

4. The regulatory agency was flexible in its response to industry's request for variances from the requirement to salvage the full 5 ft of suitable plant growth material. This flexibility didn't necessarily translate into approval of variances, but when the PSC denied such a request, it always "left the door open" by suggesting that it would be willing to reconsider its position if additional data or information were submitted. The PSC was willing to specify exactly what information it would require, such as soil moisture retention studies at the Falkirk Mine, and when data became available, it honored its commitment to change the requirements.

5. The lignite industry's position that something less than 5 ft of suitable plant growth material needs to be salvaged when overburden quality is good was reasonable and supported by research. Industry was willing to make the investment in time and money to obtain the necessary data, despite the fact there was no guarantee that the research would support its position. North Dakota lignite mining companies patiently supported their environmental staffs in their contention that the research would ultimately pay off.

6. The researchers themselves refused to make recommendations based on insufficient data, but once they felt confident in their research conclusions, they were willing to publicize and, if necessary, defend their research in the political arena, the media, and the scientific community. They conditioned their conclusions and recommendations, but not to the extent that the results of their work could not be applied to reclamation in the field.

Regulatory agencies, researchers, and the surface coal mining industry approach reclamation and research from three different points of view. The goals and objectives of the three groups and the forces which drive them often seem incompatible. Nevertheless, applying research to improve reclamation is in the best interests of all three groups, as well as the public. The process can be difficult, time-consuming, and frustrating, but it can also be successful.

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SHOULD THE EFFLUENT LIMITS FOR MANGANESE BE MODIFIED?[1]

R. L. P. Kleinmann and George R. Watzlaf[2]

Abstract.--As a result of the 1972 and 1977 Clean Water Acts, effluent mine water is limited to a 30-day average concentration of 2 mg/L manganese and a single-day maximum of 4 mg/L. These limits were selected by EPA after a survey of mine water treatment facilities indicated that these values could be achieved consistently, and that in the process of removing manganese, other trace metals were also controlled. There are, however, several reasonable arguments against such low limits. Current mining operations often face much higher levels of manganese than were considered by EPA when they established the limits. As a result, many operators must raise the pH of mine water to 10 or above, increasing their chemical treatment costs by as much as 100 pct. Precipitation of manganese then lowers the pH somewhat, but an effluent pH of 9 or even higher is common. Can the limits be safely eased? Based on recent studies, it appears that manganese is only toxic to fish at low concentrations when the stream water is exceptionally soft and pure. Except in such rare instances, manganese can be considered to be about as toxic as potassium. Our work also indicates that the other, trace metals of concern are removed at a pH below 9. It is therefore suggested that the manganese effluent limits should be reexamined in light of this information.

INTRODUCTION

Regulations, once implemented, are rarely reexamined by the enforcement agency unless such action is dictated by legislation. The threat of court action by environmental groups also acts to inhibit relaxation of regulations. It is therefore the responsibility of the affected group to periodically reexamine its regulatory limits and seek modification or exception to regulations, where appropriate. Eastern coal mine operators have repeatedly called for a less stringent limit on manganese, based on their difficulty in meeting the effluent limits, the relatively high cost associated with doing so, and their perception that the regulation serves little purpose in protecting aquatic life and downstream consumers.

It is the intent of this paper to explain the rationale for the Federal effluent limits on manganese, to reexamine those limits based on subsequent studies, and to compare the costs and associated benefits of current regulations with more lenient alternatives.

THE REGULATION OF MANGANESE

Regulation of manganese was a result of the 1972 and 1977 Clean Water Acts, which directed EPA to establish regulations that were technology-driven. Specifically the 1972 Act required regulations based on the "best practicable control technology" (BPT). In response, EPA promulgated new source performance standards for the mining industry in the U.S. Federal Register in 1976. The 1977 Act required regulations based on the potentially more rigorous "best achievable control technology" (BAT), citing 129 toxic substances, including 13 metals, that were termed "priority pollutants." Manganese was initially included on this list due to toxicity concerns (discussed later) and the discoloration problems manganese can cause to downstream water users if supplies are contaminated at concentrations of 0.2 mg/L (reviewed in Kleinmann and Watzlaf 1986.)

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As a result of a series of surveys and site visits, EPA initially established a BPT effluent limit for manganese of 4 mg/L maximum (daily) and a 30-day average limit of 2 mg/L (U.S. Federal Register 1976). The BAT regulations that followed left these limits in place. However, although the principal motivation for regulating manganese initially was its potential role as a pollutant, the impetus changed during EPA's regulatory development process. EPA concluded that manganese toxicity was not a serious problem. Downstream use was still a concern, but more important was the finding that by regulating manganese, EPA could avoid imposing regulatory limits on eight other more toxic metals (arsenic, chromium, copper, lead, mercury, nickel, selenium and zinc) that were found to be present occasionally at relatively low concentrations (Weideman 1982). Manganese was selected as a surrogate for these metals for two reasons. First, when the other priority pollutants were present, the more-common manganese was also found. Second, when manganese was removed during treatment in a conventional treatment plant by addition of alkalinity, these other metals of concern were also precipitated.

Why were the manganese limits set at 2 and 4 mg/L, as opposed to some other values? EPA, in its survey found that where acid mine water treatment plants were operating properly, manganese could be reduced to about 2 mg/L. State permits, and other effluent limits on point source discharges now typically mirror these BAT limits (cf. OSMRE program performance standards--U.S. Code of Federal Regulations 1985, Nalesnik Associates 1980).

However, the average manganese concentrations of the untreated mine waters in the survey used to develop the BAT guidelines were only 4.9 mg/L at underground mines and 17.7 mg/L at surface mines (Weideman 1982). Manganese did not exceed 63 mg/L at any surveyed acid mine water site. Our work indicates that there are today many mine sites with manganese levels much higher than those found by EPA a decade ago. Also, the average iron-manganese ratio in the EPA study was 2.6 for surface mines and 27.6 for the surveyed underground mines with acid water problems (ibid). Table 1 lists some examples of high manganese values, selected from analyses of various samples collected by the Bureau of Mines during the past few years. At many of these sites, concentrations of manganese were actually higher than those of iron. Recent laboratory tests and previous work have shown that removal of manganese becomes increasingly difficult as the iron-manganese ratio falls below about 2.5, presumably owing to the decrease of co-precipitation of manganese on ferric hydroxide (Ackman and Erickson 1986).

Table 1.- Manganese and iron concentrations in acid mine water, from analyses on record in authors' files.

Site	Total Mn (mg/L)	Total Fe (mg/L)	Fe/Mn
PA - Greene Co.	211.4	729.4	3.5
PA - Greene Co.	121.0	286.9	2.4
PA - Venango Co.	87.7	51.3	0.6
PA - Clarion Co.	91.2	31.6	0.3
PA - Clarion Co.	106.8	691.6	6.5
PA - Clarion Co.	40.7	20.5	0.5
PA - Centre Co.	130.6	193.2	1.5
PA - Clearfield Co.	30.6	50.6	1.7
PA - Clearfield Co.	138.3	116.7	0.8
PA - Clearfield Co.	160.6	131.7	0.8
PA - Clearfield Co.	122.2	13.3	0.1
PA - Clearfield Co.	82.7	39.7	0.5
PA - Clearfield Co.	116.5	106.6	0.9
PA - Clearfield Co.	102.8	42.9	0.4
PA - Westmoreland Co.	138.0	100.0	0.7
PA - Westmoreland Co.	202.4	680.8	3.4
PA - Westmoreland Co.	108.0	19.7	0.2
PA - Westmoreland Co.	79.0	38.2	0.5
WV - Upshur Co.	158.6	43.9	0.3
WV - Upshur Co.	180.0	90.6	0.5
WV - Upshur Co.	69.8	21.3	0.3
WV - Kanawha Co.	257.0	147.0	0.6
KY - Pike Co.	48.0	102.5	2.1

Thus, EPA's decision reflects the relatively high iron-manganese ratios and the relatively low concentrations of manganese that were observed in its study. The discharge criteria were not selected to satisfy perceived downstream requirements nor because such low limits were necessary for trace metal removal; they were targeted at the level observed to occur in the effluent waters of the surveyed water treatment facilities. If the sites listed in table 1 had been included in the EPA survey, it is quite possible that a higher discharge standard would have been selected, due to the difficulty of meeting such stringent limits at these sites.

THE COST OF MANGANESE REMOVAL

Cost is also a factor in determining BAT limits. If manganese must be removed by increasing the pH to 10 or above, the material costs of chemical treatment are increased by as much as 100 pct over the costs of iron removal. The alternative technique of treating to a neutral pH, aerating to remove the iron, and then using a chemical oxidant to remove the manganese increases costs by an additional 200-300 pct (Watzlaf 1985, Kleinmann et al. 1985) and fails to remove some of the other trace metals (Watzlaf 1988).

Figure 1 illustrates the costs of removing manganese by adding sodium hydroxide with optimal control of pH, as calculated for three mine sites with manganese concentrations of 12 to 100 mg/L. To meet the current 2mg/L limit, a site operator facing a typical influent manganese concentration of 25 mg/L would spend at least $300 extra for chemicals to treat a million gallons of water beyond the pH of 8 normally needed to remove iron. At a standard of 5 mg/L, this cost is reduced by $100. If the limit were 10 mg/L, chemical costs would be reduced another $100 for every million gallons of water. So, for a treatment facility handling 1 million gal/day, the annual savings in chemical costs alone would be at least $71,200 if the effluent limit was raised from 2 mg/L to 10 mg/L and half that if the effluent limit was raised to 5 mg/L.

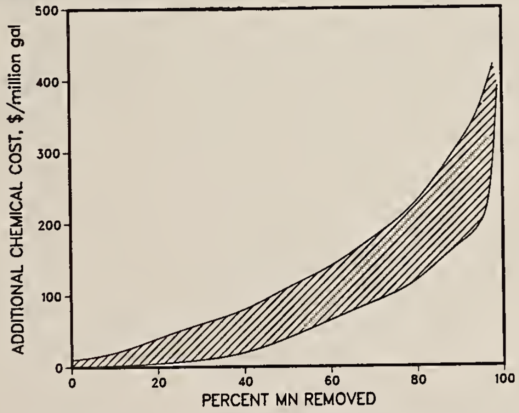

Figure 1.--Range of additional chemical costs (sodium hydroxide) for manganese removal. Chemical cost for pH adjustment to achieve regulatory compliance with iron standard is not included. Graph is based on results from three mine sites where manganese concentration ranged from 12 to 100 mg/L.

Other costs would also decrease if effluent limits for manganese were made less stringent, since increasing the pH above 9 greatly increases sedimentation basin and sludge disposal requirements. Nicholas and Foree (1979) calculated that a site that utilized sodium hydroxide to neutralize mine water that contained 74 mg/L total iron and 26 mg/L total manganese, would require 31 pct more basin area as the required pH was increased from 9 to 10, even though the amount of additional manganese removed was minimal. At another site with 4 times more iron and manganese, increasing the pH with lime from 8.7 to 9.75 increased the basin area requirements from 8,000 ft^2 to 12,857 ft^2, with an associated decrease in discharge water manganese from 3.5 mg/L to 0.2 mg/L (ibid).

Many mine operators report that fluctuations in mine water quality and quantity cause additional mine water treatment problems. This is especially true at sites where the influent iron/manganese ratio is less than 2.5, since these are the sites where the operators must raise the pH to 10.0 or higher to satisfy the existing manganese criteria. Normal fluctuations can increase or decrease the amount of alkalinity required; if the operator fails to adjust the flow correctly, the effluent water is out of compliance due to either manganese or an excessively high pH, even after precipitation of the metals brings the pH down. Also, excessively high pH treatment can cause precipitated aluminum and iron to redissolve. Water treatment thus becomes a balancing act, with potential noncompliance (and fines) an everyday occurrence.

It should also be remembered that the expense of water treatment continues long after mining has ceased and coal sales are no longer producing revenue. There are now several reclaimed mine sites where the mine water meets all of the water quality criteria except for manganese. In such cases, water treatment has had to be maintained to control manganese, typically without release of bond money. For example, one otherwise-legal discharge in Somerset County, PA, with 8 to 10 mg/L of manganese is causing a company to spend $52,000 a year on sodium carbonate (soda ash briquettes), while at the same time preventing the release of $75,000 in bond money. At another site in the same county, a $200,000 bond is being held due to manganese in the mine discharge water.

ENVIRONMENTAL CONCERNS

Before effluent limits for manganese can be modified, one must reexamine the environmental concerns that led to manganese being regulated. Since manganese is serving as a surrogate for other more toxic metals, that aspect will be addressed first. Second, the issue of fish toxicity will be discussed in some detail. Finally, there is the question of whether any downstream water supplies would be adversely affected. This is a function of site-specific dilution and existing levels of contamination, but laws that regulate manganese in public water supplies and streams would come into play if there was a problem (reviewed by Nalesnik Associates 1980).

Trace Metal Removal

A study by EPA (reported in Weideman 1982 and Going 1980) tested removal of spiked levels of the 13 metals on the priority pollutant list, including the 8 metals listed earlier. The metals of concern were all reduced to 0.07 mg/L or less at pH 8.4. Tests were also conducted in our laboratory using two mine waters with very different iron-manganese ratios, and naturally high levels of nickel, zinc, copper, and chromium. For both mine waters, zinc, copper, and chromium concentrations were reduced to less than 0.05 mg/L at pH 8.0, 7.0, and 6.8, respectively. Nickel was reduced to below 0.05 mg/L at pH 8.0 in the high iron mine water and at pH 8.8 in the low iron mine water. By way of comparison, metal finishing plants must meet BAT effluent limits of 1.5 - 2.4 mg/L for these metals. In both mine waters, reducing the concentration of manganese to 20 mg/L was sufficient to reduce all of these trace metals to 0.1 mg/L or less. This experiment is described in more detail elsewhere in this volume (Watzlaf 1988). Since a more lenient manganese limit (for example, 10 mg/L) would still require treatment to a pH of 8.5 - 9.0, it would appear that a standard of 2 mg/L for manganese is not required to assure removal of other trace metals.

Toxicity of Manganese to Aquatic Organisms

Regulators selecting a manganese standard for the mining industry found that published literature on the toxicity of manganese to aquatic organisms was confusing and apparently contradictory, with reported toxic values ranging from 1.5 mg/L to 3,400 mg/L. This wide range can be attributed to the different species of fish used in the various studies and to differences in experimental conditions. As a case in point, let us critically examine the oldest often-cited study. In 1915, Thomas reported on the effect of various substances on Fundulus heteroclitus, a small minnow. In its natural environment (salt water), the minnow tolerated manganese at all levels tested (not clearly specified, but probably up to 200 mg/L $MnCl_2$). Thomas observed, however, that the minnow could survive in brackish water, and through experimentation, determined that it could even survive in fresh water. Thomas repeated his experiments in tap water simply to see what effect the fresh water would have, and reported that 12 mg/L $MnCl_2$ killed the minnows in 6 days. Subsequent publications cite the Thomas study by reporting this toxicity value and therefore are misleading (cf. Hill 1972, Weideman 1982).

Most of the reported studies examined the toxicity of manganese in tap water. Jones (1939) found 50 mg/L manganese to be toxic to sticklebacks, while Kaemmerer and Erichsen (1951) reported that 50 mg/L was tolerated, under similar conditions. Oshima (1953) experimented with freshwater eels and reported no deaths in 50 hours of exposure to manganese concentrations greater than 2,700 mg/L. Iwao (1936), working with freshwater cyprinodonts (Orizias latipes), found 3,400 mg/L manganese to be the 24-hour toxic lethal limit. Clemens and Sneed (1959) reported that channel catfish fingerlings tolerated a manganese disodium EDTA solution for over 96 hours at concentrations greater than 500 mg/L (equivalent to 40 mg/L Mn). In tap water that contains 120 mg/L hardness,* Agrawal and Srivastava (1980) determined a 96-hour LC_{50}** for Colisa fasciatus to be 2,850 mg/L.

Trout, especially rainbow trout, are very sensitive to manganese. Lewis (1976), using distilled water, observed that the mortality of rainbow trout eggs increased from 7 pct at 0 mg/L of manganese to 12 pct at 1 mg/L, to 22 pct at 5 mg/L, and to 30 pct at 10 mg/L. Fry and adult rainbow trout were unaffected by 10 mg/L or less. England (1977), using lake water with very low hardness (2 mg/L), determined a 96-hour LC_{50} for manganese to be 24.7 mg/L. England and Cumming (1971) determined that the tolerance limit of rainbow trout fingerlings in 96-hour laboratory tests was 16 mg/L manganese for 59 to 65 mg/L hardness. Hill (1972), working with water that had a total hardness of 120 mg/L, found that the tolerance limit was 50 mg/L Mn^{2+} for juvenile rainbow trout and 88 mg/L^{2+} for adult rainbow trout, but that these tolerance limits decreased in silty water.

Much lower tolerance limits were reported in a series of papers that followed the deaths of rainbow trout at soft water (5 mg/L hardness) fish hatcheries in the Chattahoochee River watershed in Georgia and Arkansas. Although not previously considered by EPA in its regulatory decisions, these studies, when taken together, actually clarify much of the apparent contradiction found in the studies already described. Ingols (1976) found that 1.0 mg/L manganese caused the death of rainbow trout. Ogelsby et al. (1978), suggested that humic substances might also have played a role in the death of rainbow and brown trout, but this was ruled out by Grizzle (1981), who experimented with rainbow trout, brown trout, brook trout, and yellow perch in the vicinity of Buford Dam, Georgia, and found that only the first two were sensitive to low levels of manganese. This was followed by a series of bioassay experiments at Buford Dam and the associated Lake Sidney Lanier by Lehman et al. (1982) that demonstrated that suspended manganese was not significant but that the 48-hour LC_{50} for Mn^{2+} was approximately 0.65 mg/L (interestingly, Fe^{2+} showed almost identical toxicity).

It should be stressed that these unusually low tolerances have all been associated with one watershed that contains very low levels of hardness. Moreover, Lehman et al. (ibid) found that adding 10 mg/L of hardness prevented trout mortality at 1.0 mg/L Mn^{2+}. Even more important, when 100 mg/L calcium (250 mg/L hardness) was added, manganese was not harmful to rainbow trout at a concentration of 24 mg/L over a 20-hr period (Ingols 1976). The results of Hill (1972), England and Cumming (1971), Lewis (1976) and England (1977), discussed earlier, can be seen to also support the concept that hardness protects the fish from manganese.

Regarding other aquatic organisms, Lewis (1978) determined a 96-hour LC_{50} for juvenile longfin dace to be 130 mg/L manganese in water with

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*Throughout this paper, hardness is expressed as mg/L $CaCO_3$.

**LC_{50} refers to the lethal concentration for 50 pct of the test populated.

224 mg/L hardness. The flatworm can tolerate up to 700 mg/L (as $MnCl_2$) or 660 mg/L (as $Mn(NO_3)_2$) (Jones 1940). The threshold limit for Daphnia magna was 50 mg/L (as $MnCl_2$) (Bringmann and Kuhn 1959). Finally, a 7-day test at 15 mg/L of manganese had no adverse effects on crustacea, worms, and insect larvae (Schweiger 1957). In general, several investigators have concluded that manganese is only slightly more toxic to aquatic organisms than potassium (Doudoroff and Katz 1953, Jones 1939).

CONCLUSION AND DISCUSSION

Manganese can have an adverse effect on downstream water users and certain fish. In addition, the use of manganese as a surrogate for toxic metals at conventional mine water treatment facilities is a sensible alternative to regulating a long list of metals. However, the specific industry-wide effluent limits that were adopted, based primarily on observed levels of manganese attained at certain treatment plants, appear to be more stringent than required or intended. The range of water quality being treated and the treatment techniques being used have changed significantly since the EPA survey a decade ago. At the same time, more recent information that relates manganese toxicity to fish to hardness clarifies much of the confusion that previously existed in that literature. In addition, it would appear that even high levels of toxic metals are reduced to acceptable limits in treatment of mine water to manganese concentrations of 10 to 20 mg/L. Also, occasional analysis for other metals would now be a preferable alternative to treating to a high pH, although to be fair, a decade ago this option might have been difficult for the mining industry due to a lack of laboratory facilities.

A possible interim measure is a case-by-case adjustment of effluent limits. Specifically, the U.S. Code of Federal Regulations, Title 40, Chapter 1, Part 125 (1985), states that:

> (b) In establishing national limits, EPA takes into account all the information it can collect, develop and solicit regarding the factors listed in sections 304(b) and 304(g) of the Act. In some cases, however, data which could affect these national limits as they apply to a particular discharge may not be available or may not be considered during their development. As a result, it may be necessary on a case-by-case basis to adjust the national limits, and make them either more or less stringent as they apply to certain dischargers within an industrial category or subcategory. This will only be done if data specific to that discharge indicates it presents factors fundamentally different from those considered by EPA in developing the limit at issue.

Perhaps owing to the complications caused by the superimposition of OSMRE and EPA enforcement, no such exemption has ever been granted for a site with manganese problems. However, allowing such flexibility for manganese would appear to be reasonable, if the site was otherwise suitable. Specifically, if the trace metals of concern are either absent or removed at pH 9 or below, if the stream water has sufficient hardness to protect sensitive fish, and if sufficient dilution is available to avoid adverse effects on downstream users, then it would appear that more lenient effluent limits could be substituted without adverse consequences. Also, under current regulations, more lenient effluent limits for surface mines can be negotiated with the State regulatory agency after mining is completed, since the Federal effluent limits for manganese are not applicable (Weideman 1982). At sites where manganese is the only water quality problem, a favorable analysis with respect to such factors as hardness, downstream water users, etc., should result in a higher negotiated limit.

To conclude, the effluent limits for manganese were selected based on the best information available at the time; it would now appear to be a suitable time to reexamine those limits to determine if they can be made more lenient without harm to the environment.

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ESTABLISHING BASELINE POLLUTION LOAD FROM PREEXISTING POLLUTIONAL DISCHARGES FOR REMINING IN PENNSYLVANIA[1]

Michael W. Smith[2]

Abstract.--Recent changes to the Pennsylvania Surface Mining Conservation and Reclamation Act and the Federal Clean Water Act include provisions which limit liability for preexisting pollutional discharges to coal operators who reaffect previously mined areas, thereby encouraging the remining of abandoned mine lands. Both of these statutes require that baseline pollution load be established prior to commencing remining operations. The baseline pollution load is used to define premining water quality, determine effluent standards, and provide a "baseline" for evaluating the success of the remining operation in abating pollutional discharges. The baseline monitoring must be designed to accommodate the types of discharges present and must provide accurate measurement of flow rates. Observations of remining sites in Pennsylvania have shown that discharges typically exhibit one of three characteristic behaviors: 1) High flow - low concentration / low flow - high concentration response, where the flow rate varies inversely with the pollutant concentration and variability is very great; 2) Steady or damped response discharges which exhibit relatively minor or delayed response in flow rate and chemical characteristics; and 3) "Slugger" response, whereby dramatic increases in discharge are accompanied by little change in acidity concentrations, resulting in large increases in loading. Because discharges are affected by seasonal changes as well as individual recharge events, the baseline pollution load must be expressed as a statistical summary. The baseline data collection must be of sufficient duration and frequency to adequately characterize the range of conditions which are encountered.

INTRODUCTION

Recent changes to the Pennsylvania Surface Mine Conservation and Reclamation Act and the Federal Clean Water Act include provisions which limit liability for preexisting pollutional discharges when a surface mining operation reaffects previously mined areas. Both of these statutes were amended to encourage industry remining and reclamation of the thousands of acres of abandoned mine lands. Previously, under Pennsylvania's Clean Streams Law as well as the Clean Water Act, any preexisting pollutional discharge which was affected by a surface mining or coal refuse reprocessing operation became the perpetual responsibility of the mine operator, thus preventing release of the reclamation bonds.

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This created a strong deterrent to reaffecting previously mined areas which otherwise would have resulted in improved resource recovery, land reclamation, and in many cases, the reduction of acid mine drainage pollution, all without the expenditure of public monies.

BACKGROUND

The Pennsylvania Surface Mining Conservation and Reclamation Act was amended by Act 158 of 1984 of the Pennsylvania General Assembly to include provisions for remining. Regulations implementing Pennsylvania's remining law were approved by the Office of Surface Mining Reclamation and Enforcement (OSMRE) on February 19, 1986, and are set forth in 25 Pa. Code Chapter 87, Subchapter F for Bituminous Surface Mining and 25 Pa. Code Chapter 88, Subchapter G for anthracite. In January of 1987, the United States Congress similarly amended the Clean Water Act to establish modified permits for coal remining operations.

As of December 31, 1987, the Pennsylvania Department of Environmental Resources has issued 34 permits for remining under Subchapter F authorization (Fig. 1). These permits provide for the reclamation of over 1,100 acres of abandoned surface mines and daylighting of 500 acres of abandoned deep mines. A total of 112 preexisting pollutional discharges will be affected. While most permits affect only 1 or 2 discharges, up to 30 individual discharges have been affected within a single permit. Most of the permitting activity has been in the southwestern portion of the state, which is the most heavily impacted by acid mine drainage problems from abandoned mines.

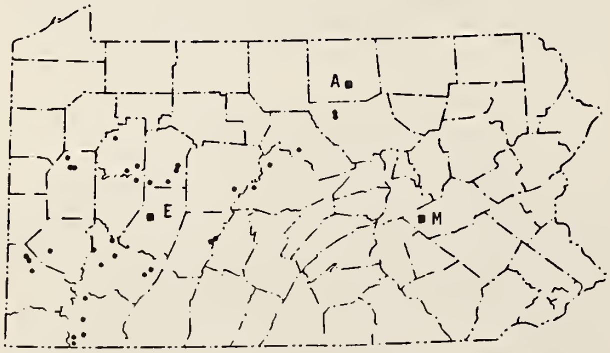

Figure 1.--Map showing location of surface mining permits issued under remining authorization in Pennsylvania and location of Arnot (A), Markson (M), and Ernest (E) Discharges.

BASELINE MONITORING

A key provision of both the Pennsylvania and Federal statutes is that the permit applicant is required to establish the baseline pollution load prior to commencing remining operations. Pollution load is the mass discharge (lb/day or kg/day) from the mine site of specific parameters such as acidity, iron, or manganese. It is found by multiplying the pollutant concentration by the discharge rate by a constant:

	English Units	Metric Units
Concentration	ppm	mg/L
Discharge Rate	gal/min	L/min
Constant	0.01202	0.00144
Loading Rate	lb/day	kg/day

The baseline pollution load is the pollution loading rate from the mine site prior to being reaffected by mining operations. A baseline is needed for two chief purposes: 1) to determine the effluent standards to be applied to the preexisting discharge(s), and 2) as a yardstick for evaluating the effect of the remining operation in abating or worsening the pollution load. In Pennsylvania, bond release is contingent upon there being no statistically significant degradation from the baseline pollution load. Accordingly, accurate determination of the pollution load during the baseline monitoring period is important to both the permittee and the regulatory authority.

Accurate flow measurement is essential for determination of pollution load. Accordingly, the baseline monitoring program must take two key factors into consideration: the behavior of the discharge and the physical nature of the discharge. Discharge behavior includes the variability of flow rates and water quality, which should be considered in planning the frequency of sampling, the length of the sampling period, and the design of flow measuring devices. The physical nature of discharges, which includes point versus non-point source discharges as well as their location in relation to the planned mining activities, can also influence flow measurement requirements. Flow from a single point-source discharge can usually be measured with a weir or other simple device. However, diffuse seepage areas, which are common on abandoned surface mines and refuse piles, usually require composite collection with conveyance to a single collection point. The most potentially difficult situation is encountered where discharges will be interrupted or relocated by mining. In this case, a thorough hydrogeologic investigation should be undertaken to plan for adequate post-mining monitoring.

Various flow-measuring devices and conveyances have been used for baseline monitoring on Pennsylvania remining sites. A catchment basin with a piped outflow is the most practical flow measuring device for low volume discharges. Discharge measurement is volumetric (e.g., using a bucket-and-stopwatch). Weirs or flumes are generally necessary for larger volume discharges. Flow measurement techniques using weirs or flumes are described in numerous sources including Eli et.al. (1980), Rantz et.al. (1982), and the U.S. Geological Survey (1977).

DISCHARGE BEHAVIOR

Observations of remining sites in Pennsylvania have shown that discharges typically exhibit one of three characteristic behaviors: 1) High flow - low concentration / low flow - high concentration response, where the flow rate varies ininversely with concentration and variability is generally very great; 2) Steady or damped response discharges which exhibit relatively minor or delayed response in flow rate with minor changes in chemical characteristics; and 3) "Slugger" response, whereby dramatic increases in discharge are accompanied by little change in acidity concentrations, resulting in large increases in loading. To examine discharge behavior in terms of baseline pollution load characterization, three mine discharges were studied (fig. 1.) The discharges were selected based on the availability of long-term water quality and flow records, and to represent the three characteristic response types as well as a wide range of hydrogeologic conditions.

Field Data

The Arnot No. 1 Discharge drains a relatively small deep mine complex in Tioga County, PA. Data were collected during the period from January 1980 through August 1983 by the Pennsylvania State University, Dept. of Geosciences under contract to the Pa. Dept. of Environmental Resources, Bureau of Abandoned Mine Reclamation (Duffield, 1985). The Markson Discharge is located in Schuylkill County, PA. and drains a large anthracite deep mine complex. Water quality data were collected from July 1981 through August 1986, and discharge measurements were obtained during portions of this period by the Pa. Bureau of Abandoned Mine Reclamation. The Ernest discharge emanates from a 110-acre coal refuse hollow fill in Indiana County, PA. Water quality and flow data were collected from March 1981 through January 1985 by the Pa. Bureau of Abandoned Mine Reclamation.

Arnot No. 1 Discharge

Figures 2a and 2b show the flow rate and acid load for the Arnot No. 1 Discharge throughout the measurement period. Both the flow rate and acid load are subject to large fluctuations with springtime peak flows in excess of 2,000 gal/min and summer and fall low flows of less than 200 gal/min. This "flashy" hydrograph response typifies high flow - low concentration / low flow - high concentration discharges. Month-by-month comparisons of the discharge data (figs. 3a, 3b, and 3c) also show large variations in flow rate, particularly during the months of March through June. Acidity concentrations vary inversely with the discharge rate, with the highest median concentrations occurring during the low-flow months of September, October, and November. However, because acid loading rates represent a combination of discharge and concentration, the acid load is found to be greatest during the peak flow months. Therefore, flow rate dominates the loading

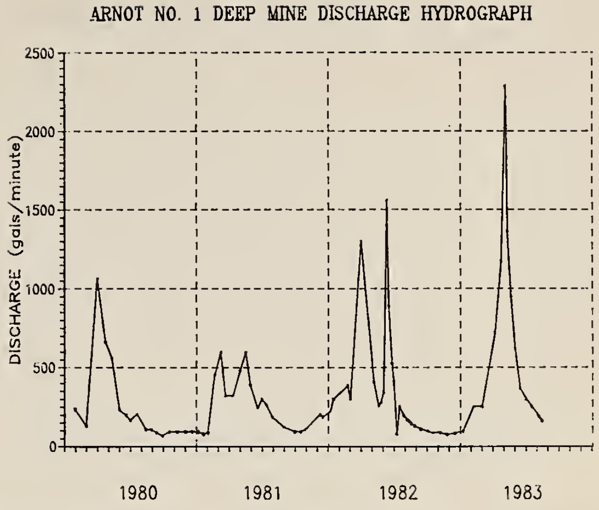

Figure 2a.--Discharge hydrograph for Arnot No. 1 Deep Mine Discharge.

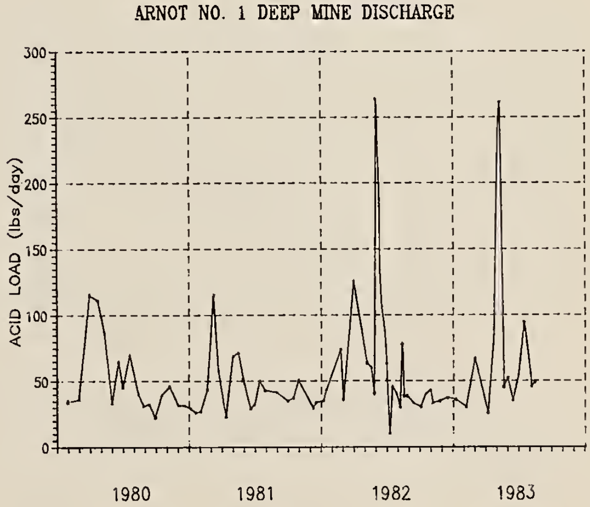

Figure 2b.--Acid load hydrograph for Arnot No. 1 Deep Mine Discharge.

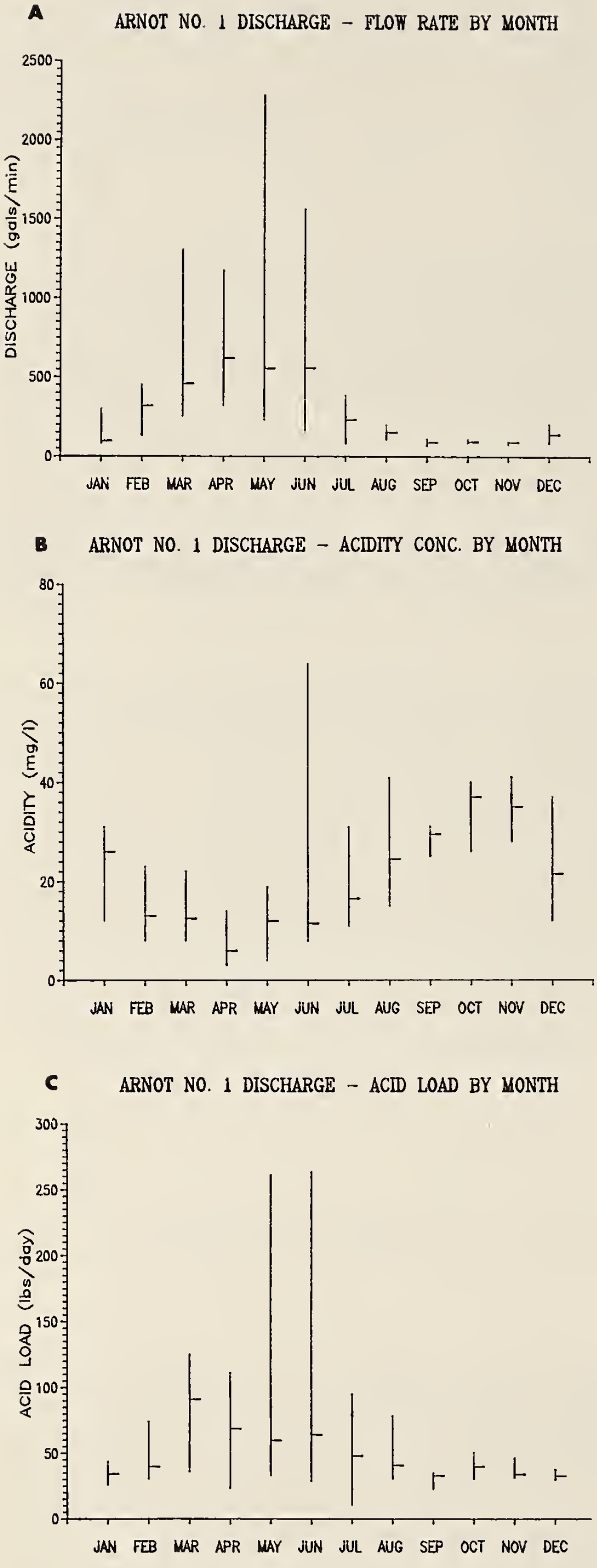

Figure 3.--Monthly median (horizontal line) and range (vertical line) values of (a) discharge, (b) acidity concentration, and (c) acid load for Arnot No.1 Deep Mine Discharge.

calculations. In Pennsylvania, the majority of preexisting discharges fall into this category. This usually occurs with non-point surface mine discharges where the capacity for ground water storage is relatively small and ground-water flow paths are short.

Markson Discharge

The Markson Discharge hydrograph (fig. 4a) shows comparatively little fluctuation in discharge rate throughout 1985, ranging from 790 to 1,900 gal/min. Similarly, acid loading rates are relatively stable (fig. 4b). Month-by-month comparisons of the entire Markson discharge data set (figs. 5a, 5b, and 5c) show some seasonal fluctuation in discharge rate, although far less than the Arnot discharge. Acidity concentrations, however, show little systematic variation throughout the year. Consequently, the distribution of acid loading rates mimics the distribution of discharge rates. Typically, steady or damped response discharges such as the Markson Discharge occur with deep mine complexes having large mine pools or surface mines with extensive ground water storage. Water quality and discharge rates remain relatively constant, owing to the large amount of ground water in storage acting as a reservoir which dampens fluctuations. Although not nearly as common, this type of discharge is the easiest to monitor since large fluctuations rarely occur. Fluctuations that do occur generally do so over longer time intervals rather than as short-term events.

Figures 6a and 6b compare discharge rates and acidity concentrations for the Arnot and Markson Discharges. As reflected in the monthly summary graphs, the Arnot Discharge shows a trend of decreasing acidity with an increasing discharge rate, apparently reflecting dilution of the mine drainage by recharge. The Markson Discharge, however, shows no systematic trend in acidity concentration with increasing discharge, presumably due to the large ground water storage reservoir and its ability to dampen changes in water quality.

Ernest Discharge

In terms of establishing a baseline, the most difficult monitoring situation is encountered with slugger discharges. This type of discharge exhibits large variations in discharge rate with relatively minor, if any, change in acidity concentrations. Consequently, rapid increases in flow result in similarly large increases in acid loading rates or acid "slugs". This appears to be the case with the Ernest Refuse Pile Discharge (figs. 7a and 7b). Flow rates vary dramatically in response to recharge events, from less than 3 to 470 gal/min. Concomitantly, acidity concentrations change very little, thereby resulting in large, rapid variations in acid loading. Presumably, the accumulation of water-soluble, acid-bearing salts in the refuse

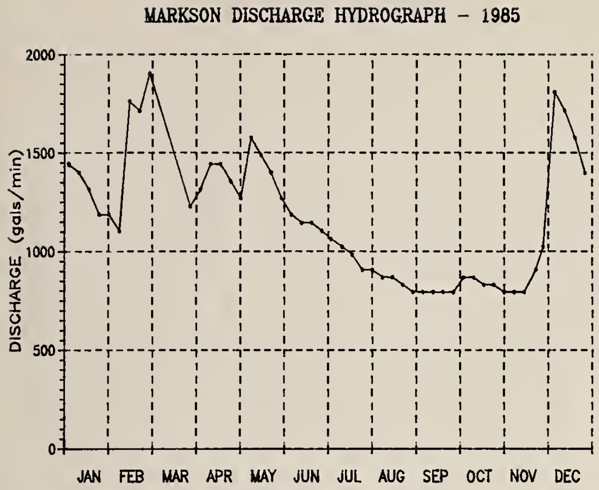

Figure 4a.--Discharge hydrograph for Markson Deep Mine Discharge.

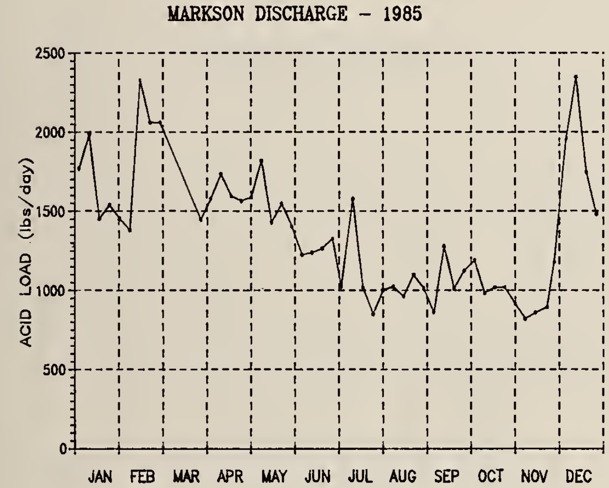

Figure 4b.--Acid load hydrograph for Markson Deep Mine Discharge.

pile allows rapid release of additional acidity following a recharge event. Figures 8a, 8b, and 8c. illustrate monthly differences in discharge and acid-loading rates. Although median loading rates are highest during the spring months, they exhibit large variations throughout the entire year.

BASELINE STATISTICAL SUMMARY

As shown by the Arnot, Markson, and Ernest examples, mine discharges are subject to large variations in pollution load, resulting from fluctuations in water chemistry and discharge rates. These variations may occur seasonally, because of changes in flow rates caused by fluctuating ground water levels, or they may occur with individual recharge events. Accordingly,

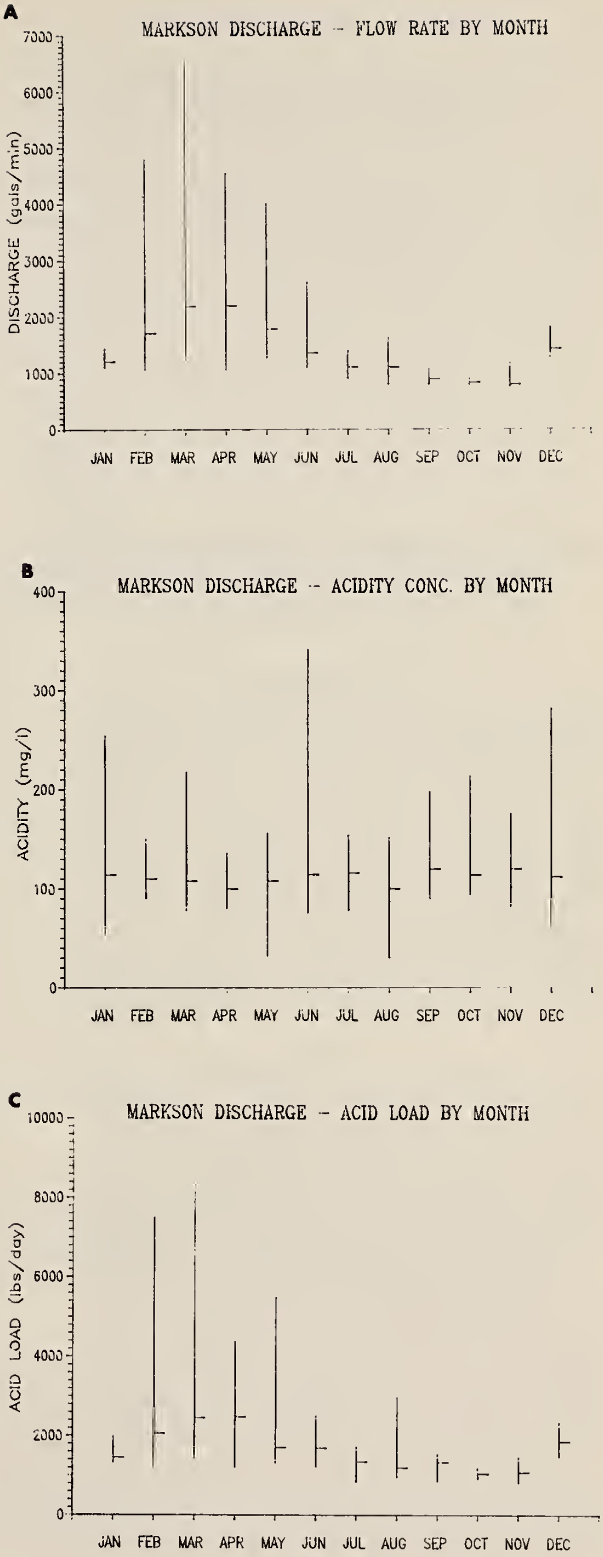

Figure 5.--Monthly median (horizontal line) and range (vertical line) values of (a) discharge, (b) acidity concentration, and (c) acid load for Markson Deep Mine Discharge. Graphs include all data from June, 1981 through August, 1986.

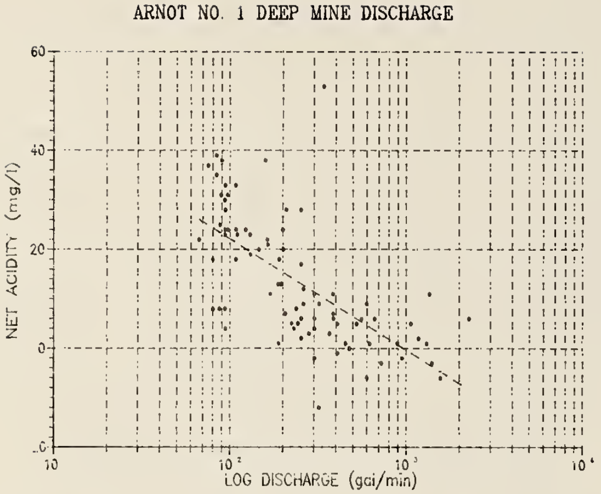

Figure 6a.--Plot of discharge versus net acidity for Arnot No.1 Discharge showing trend of decreasing net acidity with increasing discharge rate.

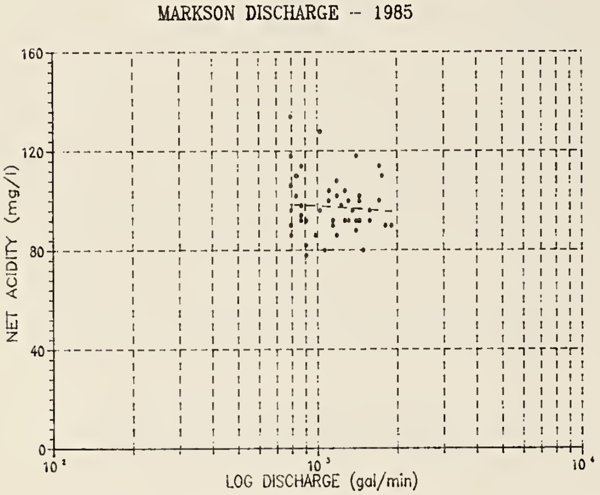

Figure 6b.--Plot of discharge versus net acidity for Markson Discharge showing lack of correlation and relatively small degree of variability in discharge and acidity values.

baseline pollution load must be represented as a statistical summary. In general, the longer the baseline period and the greater the number of samples, the more accurate the baseline summary will be. Since the baseline will be used to judge the success of the remining operation, the baseline becomes an "insurance policy" and must be accurate and statistically valid.

Various statistical parameters can be used to characterize baseline data. In Pennsylvania, baseline pollution load has been analyzed using the exploratory data analysis (EDA) techniques developed by Tukey (Tukey 1977, McGill et.al. 1978, Velleman and Hoaglin 1981). Table 1

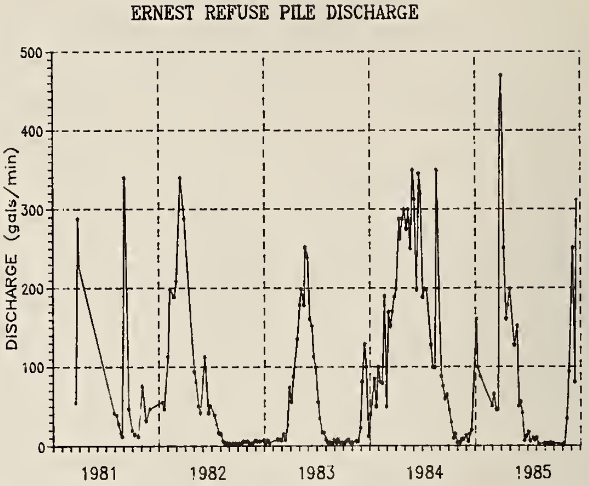

Figure 7a.--Discharge hydrograph for Ernest Refuse Pile Discharge.

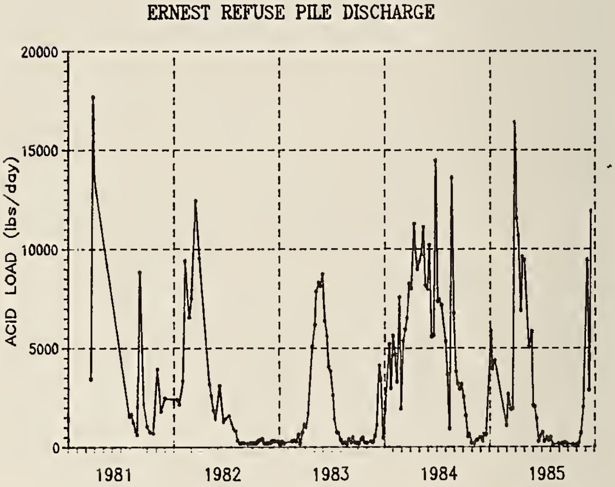

Figure 7b.--Acid load hydrograph for Ernest Refuse Pile Discharge.

presents a typical baseline summary includcluded in a permit for remining authorization. The baseline is summarized by five parameters: the range, median, hinge points or quartiles, the C values or approximate 95% confidence intervals, and the 95% confidence intervals about the median.

CONCLUSIONS

The Arnot, Markson, and Ernest discharges were examined to study discharge behavior under a wide range of hydrogeologic conditions. Several conclusions can be drawn from these studies which have implications for baseline monitoring:

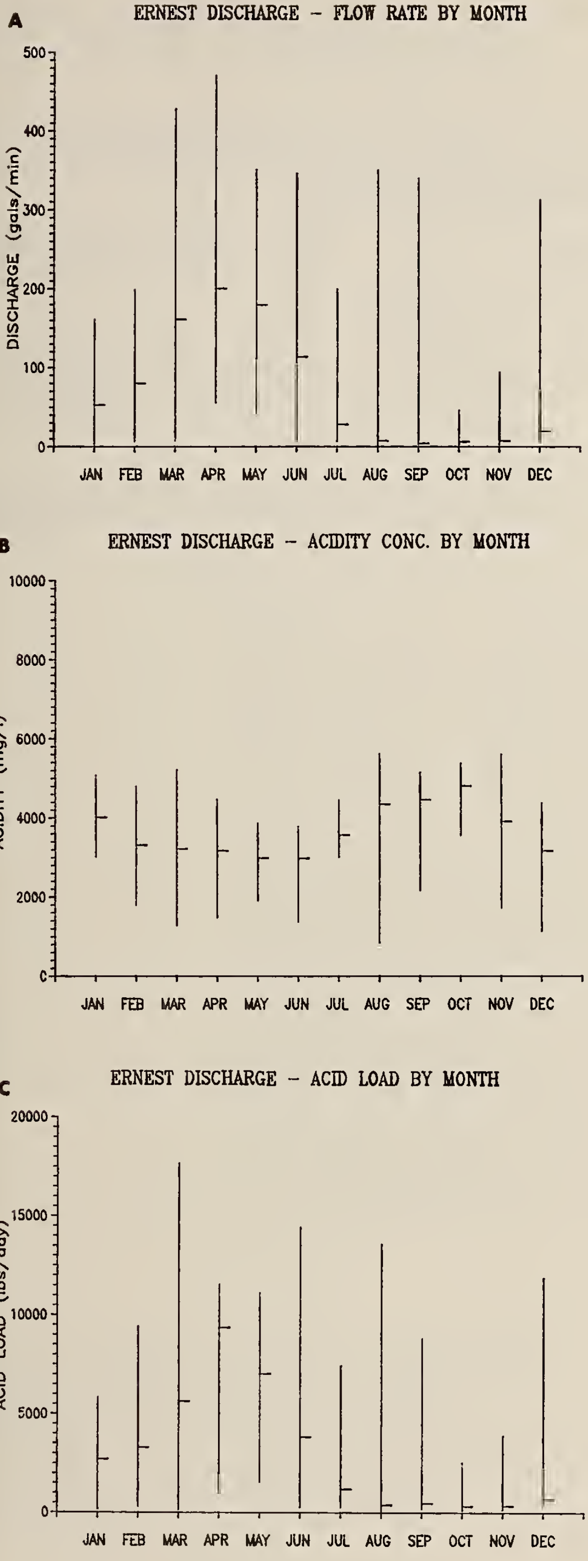

Figure 8.--Monthly median (horizontal line) and range (vertical line) values of (a) discharge, (b) acidity concentration, and (c) acid load for Ernest Refuse Pile Discharge.

Table 1.

Example of Pre-Mining Baseline Pollution Load Summary

BASELINE POLLUTION LOAD SUMMARY

PERMIT ID: EXAMPLE MONITORING POINT: SAMPLE LAT: 00-00-00 LONG: 00-00-00

PARAMETER NUMBER OF SAMPLES (N)		LOADING IN POUNDS PER DAY ACIDITY 32	 Fe 32	 Mn 32	 SULFATES 32
1. RANGE	LOW	1.10	0.01	0.04	3.76
	HIGH	188.66	8.22	4.89	421.77
2. MEDIAN		44.65	1.18	1.10	82.30
3. QUARTILES	LOW	19.00	0.17	0.47	37.02
	HIGH	73.26	2.91	2.23	167.73
4. APPROXIMATE 96% CONFIDENCE LIMITS	LOW	3.39	0.02	0.07	7.61
	HIGH	185.06	6.69	4.71	365.80
6. 95% CONF. INT. ABOUT MEDIAN*	LOW	27.24	0.29	0.53	40.36
	HIGH	62.06	2.05	1.86	124.33

*CONFIDENCE INTERVALS ABOUT MEDIAN = M +/- 1.96[1.25R/(1.35(SQR(N))]. WHERE M=MEDIAN, R=RANGE BETWEEN QUARTILES, SQR(N)=SQUARE ROOT OF THE NUMBER OF SAMPLES. FROM R. McGILL, J.W. TUKEY, AND W.A. LARSEN, 1978, THE AMERICAN STATISTICIAN, VOL.32, NO.1, P.16.

1. Baseline monitoring must be of sufficient duration to represent the entire range of variability. This generally implies at least a year of monitoring; however, in Pennsylvania the highest and lowest loading rates usually occur in the period from February through October. Since variations can also occur between successive years, one year of background monitoring does not necessarily guarantee that sufficient monitoring has been conducted to adequately characterize the discharge for future years.

2. Since individual high flow or high loading events can occur over relatively short periods of time and fluctuations can take place rapidly, the monitoring interval must be sufficiently narrow to capture these events. For a steady-response discharge, a monthly interval may be adequate. Other discharge types, however, should be monitored more frequently and the monitoring interval should be consistent throughout the baseline period to avoid biasing the baseline by collecting more samples during selected (high flow or low flow) periods.

3. The statistical summary used to characterize the baseline and to evaluate post-mining performance must not give excessive weight to a single extreme, but infrequent event.

4. Proper flow measurement is of overriding importance in monitoring pollution load, as the flow measurement affects all load calculations and appears to dominate the baseline load variation.

ACKNOWLEDGMENTS

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INSTITUTIONAL CONSTRAINTS TO PRODUCTION OF RECLAIMED MINE LANDS SUITABLE FOR DEVELOPMENT IN CENTRAL APPALACHIA[1]

Carl E. Zipper and W. Lee Daniels[2]

Abstract. -- In central Appalachian mining regions, a steeply sloping terrain restricts land use and industrial and commercial development. Flat lands that are not prone to flooding are often highly valued but construction of flat lands by coal surface mining operations is limited. The purpose of this research was to examine the institutional context of mined land reclamation planning, with an emphasis upon identification of constraints to reclamation of mined lands so as to enhance use potentials. Landowners have an interest in reclamation to improve the potential uses and values of mined lands. Actions available to landowners include paying greater attention to post-mining landform considerations during contract development, implementing adjustable royalty rate structures, and inventorying mineable lands to identify areas with landform alteration potentials. Mining firms should also have interest in implementing landform alteration mining procedures in steeply sloping terrain, due to cost and backfill stability considerations. Regulatory revisions that would stimulate application of landform alteration techniques include the modification of hollow fill construction regulations and designation of commercial timber production as land use eligible for approximate original contour (AOC) variance.

INTRODUCTION

In southwestern Virginia's coal mining region, unique terrain and economic conditions result in special land-use problems. The steeply sloping points-and-hollows terrain creates a fact of life: a short supply of land suitable for residential, commercial, and/or industrial development. But, coal seams and surface mining operations are abundant; an estimated 10 percent of the 1,500 mi^2 region have been directly affected by mining activities, the majority of which are surface mining operations (Zipper et al 1987).

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Table 1. -- Mining employment, civilian unemployment rate, and average per capita income in Virginia's coal counties and the state, selected years.

Area	Mining Employment (% of total employment)	Unemployment (% of labor force)			Per-Cap. Income ($/yr)
	(1980)	(1983)	(1984)	(1985)	(1983)
Buchanan	44.7	26.1	16.8	19.7	$8496
Dickenson	43.7	18.1	16.1	20.2	$7973
Wise	29.8	13.0	9.8	15.8	$9558
State	1.1	6.1	5.0	5.6	$12122

Source: Kraybill et al 1987.

The land use-problems of southwestern Virginia are not unique. Eastern Kentucky, southern West Virginia, and northeastern Tennessee are heavily mined areas with similar terrains. Nowhere else in the United States are the environment, economy, and social conditions of as large an area as intensively affected by mining as in central Appalachia. In 1985, 40 counties of central Appalachia, occupying 0.5% of the U.S. land area, accounted for 27% of our nation's coal production. Nineteen of those counties in the heart of central Appalachia, occupying less than 0.25% of the U.S. land area, accounted for over 20% of national coal production.

Given the recognized need for and potential value of developable sites throughout central Appalachia and the capability of the surface mining industry to move earth and stone, one would expect the industry to be busily engaged in producing reclaimed lands with enhanced use potentials as a byproduct of coal production activities. However, surface mining operations seldom use opportunities to reconstruct mined-out slopes to usable contours. Almost all reconstruct these to their approximate original contours (AOC), which, in most cases, were steeply sloping. The nature of the region's land base, the typical surface mining operations, and the effects of law on mining practice contribute to this situation.

The purpose of this research was to examine the institutional context of mined land reclamation planning so as to recommend actions with the potential to increase the rate at which flat lands with improved use potentials are produced. This purpose was approached by focusing on the goals, motivations, and influences of the three major parties to post-mining landform and land use decisions: landowners, mining firms, and regulatory agencies. The research focus was the Virginia coal region. However, topography and the institutional context of mining do not differ substantially across state lines; hence, the conclusions apply to conditions throughout central Appalachia.

DESCRIPTION OF RESEARCH

Central Appalachian Topography, Mining, and Land Use

The central Appalachian region is composed primarily of flat-bedded sedimentary rocks interbedded with coal seams and dissected by rivers and streams. Long-term geologic erosion has created a landscape comprised of flat ridgetops (the remnants of ancient plateaus), long sideslopes, and alluvial areas next to streams and rivers. Steep sideslopes with thin soils are the most common landforms.

The most intensive use of land has occurred in the limited number of alluvial areas -- streamside lands with flat surfaces and rich soils. Aside from the limited availability of alluvial areas, the problem with locating development adjacent to streams is the ever-present danger of flooding. Consequently, landscape features have had a direct effect upon economic development; the coal industry has been and remains the major employer. Other industries have been discouraged from entering the region because of a lack of suitable sites. Unemployment and poverty rates are high in the coal counties of southwestern Virginia (table 1) and neighboring central Appalachian mining regions.

The highly dissected terrain gives excellent access to numerous coal seams. Abundant outcrops favor surface mining operations. However, the overburden-to-coal ratio (the "stripping ratio") increases with distance into the mountain. Historically and at present, the surface mining industry has been based upon an ability to recover these outcropping coals economically at low stripping ratios. The most common surface mining method is contour mining, which is used where flat-lying coal seams outcrop on hillsides. Contour mining operations move laterally and, by removing the overburden, expose the underlying coal.

Contour mining methods have been profoundly affected by implementation of the Surface Mining Control and Reclamation

Act of 1977 (SMCRA). A primary facet of SMCRA is its requirement that land surface mined for coal be returned to its "approximate original contour" (AOC), except when a variance is obtained. The primary conditions for AOC variance are that the mining plan show that the after-mining landform will provide (1) an improvement of the watershed and (2) a rendering of the land suitable for a "higher" post-mining land use, such as a residential, commercial, industrial, or public use. (Agricultural land uses also qualify in mountaintop removal mining situations.) The result of the AOC provision is that now, the majority of mining spoil is hauled by truck from the mining site to the previously mined cuts where backfills are constructed to cover the highwalls. The AOC provisions of the SMCRA are extremely controversial in Appalachian areas, in part due to the perceived constraint upon the production of landforms favorable for economic development.

Recent research has shown that the near-universal application of AOC reclamation in Virginia is resulting in problems (Daniels et al 1987; Zipper et al 1986). Put briefly, construction of AOC backfills in inappropriate locales creates slope stability problems. Unstable AOC backfills may cause, at worst, massive downslope movement of earth materials or, at best, slow but persistent surface erosion that prevents vegetative establishment and causes watershed disturbance. In addition, the research has shown that it is possible to perform contour mining operations that produce broad, near-level bench areas suitable for improved use while covering all highwalls and recovering greater quantities of coal at a cost less than or equal to the cost of AOC operations (Zipper 1986).

Mining methods capable of producing favorable topographies with improved land-use potentials, relative to the steeply sloping pre-mining contours, are termed "landform alteration" (LA) methods. If properly constructed in appropriate locales, the landforms produced by LA mining techniques are more stable, have greater land-use potential, and have more favorable environmental impacts than conventional AOC landforms. However, in spite of the potential benefits to the region, applications for variance from AOC requirements are rare.

The Institutional Context

Mining and reclamation methods are affected most directly by the decisions of three parties: landowners, mining operators, and regulatory agencies.

Landowners decide which land may be considered for mining activities and what conditions may apply. Generally, landowners contract with mining firms to develop coal deposits, receiving per-ton royalty payments while the mining firm bears all costs of mining. The required work associated with the engineering and permitting function may be performed by the mining firm's in-house staff or contracted to other firms that specialize in those activities. Some larger mining firms subcontract some or all of the actual mining to smaller firms. In these cases, the larger firm leases mining rights from the landowner, performs the engineering and permitting functions, subcontracts mining operations, purchases mined coal from the subcontractor, and markets the coal to outside buyers.

The primary Virginia regulatory agency is the Virginia Division of Mined Land Reclamation (VDMLR). The VDMLR is responsible for enforcing the SMCRA within Virginia. Parallel state regulatory agencies exist in West Virginia and Kentucky, while the U.S. Office of Surface Mining Reclamation and Enforcement (OSMRE) administers the Tennessee regulatory program. Federal regulations implementing SMCRA throughout the United States are promulgated by the OSMRE. Each state agency promulgates and enforces regulations implementing SMCRA, applying the general statutes of SMCRA to in-state mining conditions. These regulations must be either consistent with or more specific than the regulations promulgated by the OSMRE. The OSMRE, in turn, maintains oversight responsibilities. Each state's regulatory programs must be approved by the OSMRE, and its enforcement efforts are monitored by OSMRE personnel.

Any firm wishing to mine coal in excess of 250 tons must file a permit application with the appropriate state regulatory agency. Within that application, the firm states its proposal to reclaim the land at issue to a specific post-mining use and describes the procedures it will follow to render the land suitable for that use. If an AOC variance is proposed, the post-mining use must be "higher" than the documented pre-mining use, and additional documentation is submitted to support the firm's ability to reclaim as proposed, including design approval by a registered engineer and certification of watershed improvement. Permit packages judged to be incomplete by the regulatory agency are returned to the mining firm with instructions detailing required remedies. When the required conditions and standards are met, the package is approved.

After permit approval, a performance bond must be posted by the mining firm. The purpose of this bond is to prevent the mining firm from abandoning the site after mining, but before reclamation. The original regulations implementing the SMCRA in Virginia stipulated that the permit contain an estimate of reclamation cost given a "worst case" scenario and that the mining firm post bond in this amount.

However, recent revisions allow firms with good reclamation records to reduce the cost of bonding through participation in a "bonding pool"; money accumulated in the pool is used for site closure and reclamation in the event of abandonment.

Interests, Barriers, and Goals of the Parties

In investigating the interaction of the parties involved in post-mining land use decisions, it was necessary to determine: (1) What interests do the landowners, the mining firms, and the regulatory agencies have in producing landforms that have improved-use potentials through mined-land reclamation, (2) what barriers hinder their abilities to work toward production of altered landforms, and (3) what are their goals?

Landowners

In general, owners of mined land should have the greatest interest in the use of landform alteration (LA) mining activities because they stand to gain the greatest benefits. Where the use of LA techniques increases coal recovery, landowners' royalty receipts also increase. Moreover, if future increases in the price of coal should make it economically advantageous to remine an area, the use of LA techniques during the initial mining operation will facilitate the remining efforts. Large, near-level areas produced by LA mining methods will serve as a favorable "base of operations", and the amount of backfilled spoil requiring rehandling will be reduced. Finally, the improved land-use potential of the reclaimed area will benefit the landowner because changes in land-use patterns in future years may make industrial, residential, or commercial development possible on currently inaccessible areas. Widespread use of LA mining techniques within a given area will make such changes more likely. In the meantime, beef cattle and softwood timber can be produced upon properly reclaimed mined lands, particularly when the presence of subsurface minerals allows the cost of landownership to be written off to future mining activities (Zipper 1987a).

In practice, the influence of landowners upon mining and reclamation decisions is, for the most part, limited. Generally, mining firms are responsible for permit preparation and mining-plan development. Participation by the landowner in these procedures will, in many cases, be contrary to established practices and, in some cases, contrary to the terms of standing contracts. Furthermore, an AOC variance application adds to the cost of permit preparation and may add to the time required for permit approval. This raises the question of whether it would be economically advantageous for the landowner to bear these additional costs. From a financial standpoint, such costs will only be advantageous if the landowner expects the value of profits from the planned land use to be greater than the increase in permit preparation costs. However, the costs must be borne in the present, while profits are expected to provide income in future years. The ability of the expected profits to compensate for present-day costs is handicapped by the long period that commonly occurs between the start of permit preparation and the conclusion of mine reclamation activities (typically a 3 to 5 year period) and by the risk that a change in the price of coal will postpone or prevent mining.

The time lag between permit preparation and post-mining land use implementation also hinders the landowners' ability to implement reclamation technologies developed through research. For example, the development of environmentally sound, cost-effective methods for constructing residential waste disposal systems (modified septic drainfields) on mined lands would have a tremendous impact on the feasibility of establishing residential housing on mined lands. Perhaps the next few years will bring development of such methods. However, mine planning decisions are being made today that will determine the post-mining land uses to be implemented on areas to be reclaimed in future years, thus potentially limiting the immediate impact of such development.

In some areas, corporations specializing in mineral and timber development are major owners of land mined for coal, owning both mineral and surface rights. However, in other areas, the land ownership pattern is extremely complex; mineral rights to the various coal seams are under a variety of ownerships. In some cases, these "owners" are not identifiable as single parties, but constitute complex assemblages of the heirs of an earlier individual owner. Complex surface and mineral rights ownership patterns are a definite hindrance to the establishment of improved post-mining land uses, due to the difficulties of achieving consensus.

Another problem results from the existence of subsurface coal below many surface-mining sites. The presence of deep mines can render the land surfaces unsuitable for development that requires major building construction or paved roads because of the danger of subsidence. Thus, in most cases, agricultural or horticultural enterprises will be the most feasible land uses currently eligible for AOC variance. However, many Appalachian landowners are unfamiliar with such enterprises, traditionally uncommon within the coal regions. Also, success will depend upon the mining operator's ability and willingness to prepare a deep, productive soil upon the mined area.

Developing contractual arrangements to effect such practice is hindered by current long-term contracts and by the fact that, in many cases, the landowner does not deal directly with the subcontracting firm that conducts actual mining.

Mining Firms

There are situations where the mining firm should have an interest in shifting from the AOC mining techniques to the LA mining techniques. Primary among these are the operational cost advantages of LA mining in favorable locales, of having greater operational flexibility, and of reducing the incidence of working machinery on steeply sloping surfaces (Zipper 1986, Zipper et al 1986).

However, these advantages might be offset by three major factors. First, in many cases, any potential profits from a post-mining land use would not benefit the mining firm. This fact reduces the mining firm's incentive to engage in unfamiliar mining and reclamation techniques. Second, current commonly used mining-cost estimating methods are, generally, quite time consuming and not always accurate. Thus, the mining firm seldom has the ability to estimate, during permit preparation, the comparative cost effects of alternative mining and reclamation plans.

Third, there are two large, external risks to profitability to which the mining firm may become more vulnerable through engagement in LA procedures. The first is a potential increase in the cost of meeting SMCRA regulations. Engagement in LA procedures could be perceived as opening the door to increased regulatory costs in two ways: by attracting increased regulatory scrutiny and by causing entry to an area of unfamiliar regulatory interpretation. The second external risk is imposed by potential changes in the price of coal. In conventional (AOC) contour-mining, the mining operation proceeds linearly along the outcropping coal seam; unanticipated price drops can be accommodated by adjusting the stripping ratio or by delaying or stopping mining. The LA techniques will put the firm in a more vulnerable position, as the landscape reconstruction activities, once initiated, will often require long-term commitments and more complex spoil-handling plans than conventional AOC methods. These consequences reduce the operator's ability to respond to coal price changes and may increase performance bonding requirements.

Regulatory Agencies

State and Federal regulatory agencies should also have interests in stimulating the use of LA mining techniques on steeply sloping terrain. First, it is in the public interest, and also in the long-term interest of the mining industry, to prevent construction of AOC backfills where they are not appropriate. Appropriately constructed LA landforms will have more favorable environmental effects (e.g., less surface erosion and greater stability) than steeply sloping AOC backfills (Daniels et al 1987). Second, it will benefit the local economy to allow the mining industry to produce sites suitable for development. Third, the present time is a good time to work toward reclamation policies more appropriate to the steeply sloping terrain of the Appalachian coal mining regions; currently, the price of coal is relatively low and, consequently, there is a low level of surface mining activity. Should coal production expand because of a sharp or even modest price increase, regulatory agencies would have tested and have in place appropriate policies rather than have them under development.

Regulatory agencies are hindered from taking direct action by the SMCRA's constraints and by the intricacy of the Federal-State oversight system. However, they do have the ability to promulgate policy changes through the rules and regulations implementing SMCRA.

RECOMMENDATIONS

Landowners should have strong interests in developing widespread use of LA mining techniques that can render steeply sloping pre-mining contours into post-mining landforms capable of supporting "higher" uses. However, in the current context, landowners have only a minor influence over mine planning and reclamation. To increase their influence, landowners will have to work more closely with mining firms during permit preparation procedures. Private landowners who plan to mine small individual tracts will need to insure mining firm cooperation during contract development. Corporate landowners might use royalty reductions as bargaining chips when negotiating the mining plan with mining firms. Similarly, the credit and assets of the corporate landowner can be used to provide cooperating mine operators with performance bonds or to reduce the cost of such bonds. An adjustable royalty rate structure responsive to the price of coal would allow landowners to bear a portion of the price risk for mining operators who are leery of long-term commitments.

These tools can be used most beneficially by landowners who inventory mineable lands to identify areas suitable for landform alteration with favorable pre-mining contours and geology. The ability to develop altered landforms will be favored by proximity to present or planned public services and by the absence of subsurface mines or substantial unmined coals. Landowners may wish to exert control over deep mining activities adjacent to potential LA sites, since the deep removal of surface-mineable coal will prevent future economical engagement in LA surface-mining methods. The development of a livestock industry in the region will enable landowners to use altered landforms underlain by deep coal for livestock production. The establishment of programs by corporate landowners to lease acreages to individuals for livestock production will help develop such an industry.

In the long run, mining firms should have interests in more widespread use of LA mining techniques because of the positive effects these techniques have upon mining costs and because these techniques may allow coal to be mined economically in some excessively steep areas that are unsuitable for AOC mining. Mining firms wishing to engage in LA techniques can benefit by concentrating attention on reclamation activities during current operations and by developing a record of good reclamation. Regulatory personnel are required, when evaluating variance applications, to determine whether there is a "reasonable likelihood" that the land reclaimed will be suitable for the proposed land use. The demonstrated ability of the mining operator to construct suitable surface soils and landforms may be considered by regulatory personnel when evaluating the "reasonable likelihood" criteria.

Regulatory personnel can also affect the frequency at which favorable landforms are produced and stimulate mining firms to examine alternative mining methods by restricting AOC mining to appropriate locales and by placing closer scrutiny on AOC mining activities. Regulatory authorities might also adopt a stance of openly advocating the use of LA procedures in the steeply sloping points-and-hollows terrain where it can be applied most effectively. This could be accomplished by focusing favorable publicity upon environmentally sound operations that produce lands with favorable characteristics for development in locales where they are needed. Such a step would eliminate any perceived stigma from AOC variance applications.

Another, and indeed a giant, step would be to designate production of commercial forest as a "higher" land use eligible for AOC variance. The use value of land devoted to commercial forest is greater than that devoted to unmanaged forest, and the deep, productive soils required for profitable softwood timber production would contribute to watershed improvement. Such a step would eliminate a current paradox: the eligibility of livestock production enterprises for AOC variance in mountaintop removal mining operations when commercial timber production is ineligible. This situation is paradoxical because the potential profitability of softwood timber production on appropriate sites can be greater than that of livestock production, while the environmental impact of timber production is likely to be less (Zipper 1986).

CONCLUSIONS

In central Appalachia, there exists a unique opportunity to improve land-use potentials through use of appropriate surface mining operations. All the elements required to effect this change are in place. In order for the change to occur, there must be increased understanding by and cooperation among landowners, mining operators, and regulatory authorities. Because there is a relatively low level of surface mining activity currently, the present is an opportune time to establish precedents required for effective and widespread use of landform alteration (LA) mining procedures.

If surface coal mining operations are to produce reclaimed sites with development potentials, as are sorely needed in many central Appalachian communities, it is essential that those uses be planned at the outset of mining. Spoil handling and reclamation must proceed with the specific objective of supporting that use so as to prepare a reclaimed landscape with appropriate characteristics. Once mining and reclamation are complete, it becomes very costly to rework a mining site. The future ability to construct usable lands as a byproduct of surface coal production operations will be limited, as near-surface coal reserves are being rapidly depleted.

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COMPETITION IN THE COAL FIELDS AND THE ENFORCEMENT OF SMCRA[1]

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Last August marked the tenth anniversary of the enactment of the Surface Mining Control and Reclamation Act (SMCRA), hailed as a comprehensive approach to establish national minimum standards for the mining of coal and the reclamation of land. The law has not accomplished what Congress or the citizens of the coalfields had envisioned. Mining abuses still flourish, standards vary from state to state, and thousands of acres of abandoned mined lands remain as scars on the landscape.

SMCRA is one of the most comprehensive land-use laws ever promulgated. It mandates planning from outset to conclusion. A mineral developer must analyze conditions before mining, must submit a proposal on how mining activities will be conducted, and must have a plan for achieving post-mining restoration of the affected land to a condition capable of supporting the uses which it was capable of supporting before mining.

The goals of SMCRA are laudable. The past history of mining in our country resulted in thousands of miles of streams clogged and polluted with sediment and acid mine drainage and tens of thousands of acres of mined land unreclaimed from surface mining, in addition to the legacies of unregulated national underground mining, which include continuing subsidence of mined-out areas, huge culm piles, and untold numbers of serious, long-term acid mine discharges.

Citizens across Appalachia began organizing protest groups in the late 50's and 60's. When state government failed to meet their citizens' concerns by establishing stronger state programs, the battle was carried to Congress. Using the Pennsylvania mining regulatory program as a discussion model, Congress debated the issue of a national regulatory program for nearly 10 years. Twice legislation was passed, which was vetoed by two different Republican presidents.

In 1977, under a Democratic administration, SMCRA was passed and signed into law. In the Act's Statement of Findings, Congress said, ". . . surface mining and reclamation are now developed so that effective and reasonable regulation of surface coal mining operations by the States and by the Federal Government in accordance with the requirements of this Act is an appropriate and necessary means to minimize so far as practicable the adverse social, economic and environmental effects of such mining operations. . ." Furthermore, it found, ". . . surface mining and reclamation standards are essential in order to insure that competition in interstate commerce among sellers of coal produced in different States will not be used to undermine the ability of the several States to improve and maintain adequate standards on coal mining operations within their borders. . ." (U.S. Code of Federal Regulations 1977).

Throughout the legislative debate over SMCRA, Congress repeatedly registered concerns over the propensity of states to underregulate and underenforce environmental constraints on mining. The House bill provision, which prevailed at Conference and which contained language which became part of Section 521 (a) (i) as finally adopted in SMCRA, summarized their conviction that states, if allowed to fashion and administer their own state programs, would not enforce the Act as intended:

> For a number of predictable reasons - including ... the tendency of State agencies to be protective of local industry - State enforcement has, in the past, often fallen short of the vigor necessary to assure adequate protection of the environment ...
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> While it is confident that the delegation of primary regulatory authority to the States will result in fully adequate state enforcement, the Committee is also of the belief that a limited Federal enforcement role as well as increased opportunity for citizens to participate

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[1] This paper represents solely the author's opinion and is published, virtually as received, out of respect for the wishes of the environmental community that this paper not be subject to normal review procedures.

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> in the enforcement program are necessary to assure that the old patterns of minimal enforcement are not repeated. (U.S. House of Representatives, 1977).

The compromise arrived at in SMCRA was that states could apply for primary enforcement authority for the Act but that the Federal government would reserve for itself an oversight authority to ensure that the Act was enforced and that reclamation was achieved. The problem has become the changing philosophy of the Federal administration. Under the Carter presidency, the philosophy of the Federal Office of Surface Mining (OSM) was that the Act would be interpreted strictly and that Federal oversight would be zealous. Under the Reagan administration's 'New Federalism' approach, the Act has not been interpreted to preserve the Federal and has, in fact, been eroded of much of the driving force to achieve "national minimum standards." OSM has exaggerated the emphasis on the role of states under approved programs to the point of distorting the enforcement structure of the Act and the proper overlay of Federal enforcement over state program enforcement.

The widely divergent philosophies of Federal administrators from one of cooperative state-federal enforcement with a substantial role for the state to one of an overriding role for the state and an ineffective oversight role for the Federal government has produced a climate of uncertainty and disarray for the industry, for regulatory agencies, and for the general citizenry.

James Lyon of the Environmental Policy Institute in Washington, D.C., a citizen organization that often takes the lead on mining issues, says that OSM has allowed the states' effort to "slide to the lowest common denominator. When you allow a state like Kentucky to go off the edge, there is tremendous pressure in the other states for a falloff there, too, because of the cutthroat competitiveness of the market." (Courier-Journal 1987)

The climate of uncertainty is focused on the Federal quidelines upon which state programs are based under the law. In 1981, former Interior Department Secretary, James Watt, in the name of 'Regulatory Reform,' ordered the OSM to rewrite 90 percent of its regulations. National and grassroots environmental and citizen groups, claiming the changes violated the intent of the Act, challenged Watt's final rules in federal court. The groups received an overwhelming victory when in 1984-85 the court ruled to remand virtually every major change sought by the administration. Over the past year, after almost two years of delay, the OSM is beginning to make final a few of its rewritten regulations. The environmental groups involved in the litigation claim the new regulations blatantly ignore the Federal court's ruling on these issues and, for the most part, take the exact same line as the initial changes. The third revision of national regulations is now being litigated.

The Watt-directed changes in regulation - those changes challenged in court by the environmental coalition - in general relaxed specific (or, as charged by industry critics, 'cook-book') standards established in the 1979 regulation package to more general ones which allow state interpretation. Allowing states such broad interpretation encourages widely divergent state programs. The Act contemplated minimum standards for coal mining and reclamation that would put coal producers on a more or less equal footing; however, competition is rife in the coalfields again.

The administration's eagerness to turn the program over to states as part of the New Federalism approach may have been a critical mistake. At the end of the Carter administration, states had lead enforcement duties at only 11 percent of the nation's strip mines. Within 20 months after the Reagan administration took office, more than 80 percent were state regulated. In a recent comprehensive series in the Louisville, KY, Courier-Journal, state leaders were asked their opinion on why state programs were in trouble:

> 'For those states that had very little regulation - Virginia, Kentucky, Alabama - it was a very, very traumatic change and they simply weren't ready to do it themselves,' said coal-industry consultant Alan K. Staff. 'The industry in those states very seriously resisted the Act and compliance with it. And there are those who say they still are, that Kentucky especially is still fighting it.'
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> 'The states were in no shape to take it (mining regulation) over,' said James Fleming, energy adviser to Kentucky Democratic Sen. Wendell Ford, a staunch industry ally.
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> Longtime coal operator William B. Sturgill, whose name is synonymous with strip mining in Eastern Kentucky, said the 1977 law 'hasn't been administered in such a way as to make a contribution to the production of coal or to the environmental constraints we all wanted to achieve.' (Courier-Journal 1987)

Twenty-four states now have primacy responsibility for enforcement. According to General Accounting Office reports, state program operations have not been effective (U.S. General Accounting Office, 1986, 1987). The GAO surveys found that states were citing less than half the violations in their coalfields - many of which were of serious potential to harm the environment. Nationwide, more than $180 million in civil strip-mine fines remain uncollected. Kentucky alone has $60 million in uncollected fines and also can boast of having more than 2,000 unabated cessation orders which have not been enforced. Kentucky is also singled out as the state harboring the largest number of the scofflaws called 'wildcat' miners, those who don't bother with permits, backfilling, or severance fees at all. Border counties in Southwestern Virginia and in Tennessee also have their share of wildcatters. OSM Director Jed Christiensen announced last August the formation of a 12-person Federal strike force to combat wildcat mining.

One loophole in SMCRA, the two-acre exemption operation which was free from severance taxes and reclamation requirements, was quickly seized upon by unscrupulous operators in Western Virginia and Eastern Kentucky. Small, independent operators weren't the only ones to reap profits from two-acre operations. Large companies, including one of the largest corporations in the nation, created through sub-contractors "strings of pearls" operations which connected numerous two-acre mines. Legitimate coal producers in those areas were put at a distinct competitive disadvantage. Last spring, with support of both industry and environmentalists, Congress closed the loophole, abolishing the two-acre exemption.

One area which can be particularly pointed to as one which encourages competitive disadvantages for coal producers is the reclamation bond. The divergence in bonding rates is a significant factor in comparing state programs and looking at the costs to industry in each state as well as comparing costs to the environment in terms of potential threat of increased abandoned acreage.

SMCRA requires mine operators to post a bond to assure that mined lands will be adequately reclaimed if the operator is unwilling or unable to do so. How much should that bond be? In my own state, Pennsylvania, it is estimated that at least $6,000 per acre is necessary to cover public reclamation costs. Other states have different estimates. Ohio reclamation officials say it costs their state at least $5,500 per acre. And, it should be borne in mind, such last ditch reclamation is rarely the return to pre-mining conditions that is the preferred form of reclamation under the Act.

Although the mining industry was the foremost advocate of allowing state-by-state divergence from the Federal guidelines, it now rails against the difference in the cost of doing business from one state to another. Pennsylvania industry spokesmen maintain it is two to three times as expensive to mine coal in Pennsylvania as it is in West Virginia or Kentucky, for example. Much of that cost is found in the differing bonding rates.

Over the past summer, I conducted an informal survey of the bonding practices and bonding levels in eight Eastern mining states: Indiana, Kentucky, Pennsylvania, Virginia, Illinois, Ohio, Tennessee and West Virginia. When I summed up the results of the survey, the overwhelming impression was that bonding is, on the whole, inadequate and there is little similarity in the way programs are bonding surface mine operations.

Bonding the mining area is one of the big cost items in mining. That cost, especially in the Eastern region of the country, should be comparable from one state to another. Right now it isn't. The required bond can be as high as $10,000 an acre to bond in Pennsylvania or Illinois. In Ohio, it cannot cost more than $2,575 an acre, less than half of what the state says it costs per acre to reclaim the site if the state has to assume reclamation responsibility. In West Virginia and Tennessee, an operator can obtain a bond for $1,000-$2,000 an acre even if he is removing a mountain top and creating a valley fill.

My informal survey also brought out one particularly disturbing fact: you can't rely on the Federal government to establish adequate bonding rates. The Office of Surface Mining is now administering the Tennessee program, the only state program under Federal administration. Their bonding procedure, however, is setting bonds among the lowest in the Eastern states. Two examples of recently permitted operations reveal the following bond amounts:

1) An area mine with an average of 20 feet of overburden - 270 acres bonded at $177,000 ($655 an acre).

2) Another area mine where a variance was granted to accommodate a drag-line operation, extending the allowable pit opening from 1800 feet to 4200 feet and allowing three spoil piles - 682 acres bonded at $1,425,000 ($2,089 an acre).

The initial Tennessee primacy program, taken over by OSM, bonded at $1500 an acre - clearly inadequate. The Federal program - based on the examples above - appears to be no improvement.

Both state primacy programs and OSM calculations on bond requirements for permitting assume prompt inspection and enforcement activity - in other words, strict adherence to contemporaneous reclamation requirements. What happens to bond adequacy when strict enforcement is absent? The public has neither assurance that adequate bonds are being set nor that there is a national standard in operation.

Most states claim that they have had so few cases of forfeiture on permanent program operations that it is impossible to accurately assess adequacy of bond levels. OSM recently conducted a review of four of the first five permanent program bond forfeitures in Kentucky. Of the four sites, OSM calculated the necessary amount to reclaim to be two to three times more than the state bond amount for the sites. In all four cases, the sites will not be reclaimed to permanent program standards. The OSM noted other program failures in connection with the sites: a total of $244,735 in civil penalties had been assessed against the operations and all penalties remained outstanding. (Tipton 1987)

Another area of concern to citizens in the coal fields is what happens to the acreage abandoned in the interim period between enactment of SMCRA and the approval of state primacy programs? Those operations were mostly the fall-out of the end of the 'energy crisis.' Operators hoping to cash in on a new demand for coal went bust, they could not re-permit under primacy program requirements, and their mines were left unreclaimed. The abandonments neither qualify for Abandoned Mined Lands severance funds nor for permanent program bond forfeiture funds. For want of a better term, I call those abandonments "Notch Babies." There are more than 31,000 acres of Notch Babies in the Eastern coal fields, over 20,000 acres in my own state of Pennsylvania.

All those mines were bonded at much less than the cost of public reclamation. Yet, except in a few cases, not even that limited bond has been recoverable. In many cases, the bonding companies have also declared bankruptcy. As the insurance companies also suffer financial problems, the market in general has become even tighter. Even reputable, well capitalized mining companies are having problems securing surety bonds. Clearly, further Federal legislation is needed to cope with the problem. States do not seem able to either control surety companies nor to initiate adequate alternative bonding systems.

Arguments continue to be heard here in Pennsylvania that our relatively strong regulatory program should be weakened so that our industry can compete more effectively with that in neighboring states. The industry is supporting several initiatives that would reduce the Pennsylvania program to its least common federally required minimum. It has convinced the State Senate Environmental Committee to approve a resolution calling for a review of state mining industry regulations to allow more competitive coal marketing. Complying, the Department of Environmental Resources in Pennsylvania recently reviewed recommendations of an industry task force and consented to numerous changes in administrative procedures. The Department has been less willing to reduce environmental regulations.

Conservation groups in Pennsylvania, as well as across the nation, decry the drive to weaken state programs as being shortsighted and neither in the states' or nation's best interests. Other states which have failed to regulate their industry under the guidelines of SMCRA now are paying the price with Federal sanctions, controversy in state legislatures, and citizen agitation and litigation. Their environments are paying the price in new degradations of land and water resources and a new generation of abandoned mines.

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PROGRESS TOWARD ABATEMENT OF MINE FIRES IN THE ANTHRACITE COAL FIELDS[1]

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Abstract.--Fires in abandoned underground mines pose a significant environmental hazard because of emission of toxic gases (typically carbon monoxide, hydrogen sulfide, and carbon dioxide), surface fracturing, subsidence, and ignition of surface fires. A minimum of 50 fires have occurred in the abandoned mines of the anthracite coalfields of Pennsylvania since 1945. Through the combined efforts of the Office of Surface Mining Reclamation and Enforcement, the U. S. Bureau of Mines, and Pennsylvania Department of Environmental Resources, 20 of these fires have been controlled or abated, most by excavating overburden and quenching heated materials. Another 13 have been controlled or abated by private colliers. Of the 33 "controlled or abated" fires, 13 have been "controlled" by constructing incombustible barriers around the fire, surface sealing, or allowing the local mine pool to inundate the area. Because these fires may still be burning, future problems could result if surface land uses are not planned. At least 17 mine fires are presently burning uncontrolled in the anthracite fields, but are not believed to pose a threat to life or property. Abatement (control or extinguishment) of three fires is underway or is scheduled in coming years. Possible abatement of another three fires is under study. Since 1980, a total of seven new underground mine fires have been discovered in the anthracite fields, and it is projected that a rate of one or two new fires per year is likely to continue into the future. The major proximate causes of new mine fires are spread of surface fires from coal refuse (culm) or igniting of exposed coal seams in strip mine pits. However, both typically result, in turn, from burning of illegal trash dumps.

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INTRODUCTION

Fires in abandoned underground mine workings have been a problem in the anthracite coalfields since the 1850's. Hazards typically associated with underground fires include smoke and toxic gas emissions (generally carbon monoxide, hydrogen sulfide, and carbon dioxide), surface cracking and subsidence, ignition of surface fires, and consequent property devaluation. While mining was underway, underground fires were fought by trained mining company personnel. However, the abandonment of the anthracite mines and dissolution of mining companies have meant that most underground anthracite mine fires must be fought by government. Since most of the underground workings are now inaccessible these fires cannot be attacked directly without the costly removal of overburden.

This paper discusses the present status of 50 underground mine fires which have been discovered in the anthracite fields since 1945. Although other fires are known to exist, insufficient information was available to include them in this report. Other fires may be burning, dormant, controlled, or abated, but have not been reported. Where abatement (i.e. control or extinguishment) activities have been undertaken, data summarizing the location, abatement method undertaken, and the year of completion as well as the organization fighting the fire are shown. For a group of completed projects the approximate costs of abatement, surface area affected, and other pertinent and available data are presented.

Some of the fires listed here are discussed in Chaiken et al. (1983). Other information was obtained from the Bureau of Abandoned Mine Lands of the Pennsylvania Department of Environmental Resources (DER), the Bureau of Mines (BOM) Wilkes-Barre Office files currently being maintained by the Office of Surface Mining Reclamation and Enforcement (OSMRE) in Wilkes-Barre, PA, or from consultants currently engaged in fire control work in the anthracite field.

BACKGROUND

Geological Setting

There are four anthracite coalfields underlying a surface area of 484 $mi.^2$ situated in the north and central sections of eastern Pennsylvania. The geology is sedimentary and metamorphic with shales, slates, sandstones, and conglomerates predominating. Folding, faulting, and steeply pitched bedding planes are extensive. The coal measures occur in multiple beds, varying in thickness from 1 ft. to greater than 50 ft.

Mining has been extensive since 1850, but has declined since 1945. General mining practice was a modified type of room and pillar system directed against the drainage contour in areas with less than 10° of pitch. In steeper areas, a chute and battery system was used. Extraction ratios varied from 50% to 90%. Multiple-bed mining was common throughout the coalfields, but pillar columnization was not practiced. Due to the multiple-bed mining, ventilation was provided by a complex system of inside slopes, tunnels, gangways, and airways which consequently provided a means of communication between the coalbeds. The result of the extensive and random mining in a complex geologic setting is frequent subsidence which defies pattern or prediction and which enhances natural ventilation, and disrupts the effect that manmade barriers, such as coal chain pillars, permanent ventilation stoppings, or other barriers, have on fire propagation. Coal outcrops were randomly strip mined to the excavation limits (10'-50') of available machinery. The strip pits were generally neither backfilled nor reclaimed, and exposed coal was left at the base of the pit.

All underground fire events have occurred in mined areas with less than 1,000 ft. of overburden. Presently a system of mine water pools (i.e. interconnected mine workings flooded by the local water table), separate in each field but persistent through the measures, limits the depth of the fires to a maximum of about 500 ft. and generally 200 to 300 ft.

Anthracite Coal Characteristics

Anthracite has the highest rank and grade of coals. Anthracite has a fixed carbon content that ranges from 92% to 98% and a volatile matter content of from 2% to 8%. It burns with a short, pale blue flame, emits little odor, and does not coke. (Stefanko, 1979) It also has an extremely low heat of conductivity and an ignition temperature ranging between 815° F and 878° F, indicating that the material may be both difficult to ignite and to extinguish. (Scott, 1944)

RESULTS

Since 1945 a minimum total of 50 mine fires have occurred in the anthracite coalfields of Pennsylvania (table 1). Of these, 33 have been controlled or abated, and 17 are presently burning. In the abated/controlled category, 20 fires have been successfully fought by government agencies (DER, BOM, or OSMRE) while another 13 fires have been successfully fought by private colliers. These 13 fires include three fires (Humbert, Pine Hill, Wadesville) considered dormant solely on the basis of no surface evidence of fire and three fires (Susquehanna #8, Lansford #4, and Primrose) which were extinguished by the "natural" rise of the mine pool which

Table 1.--Current status of 50 underground anthracite mine fires currently burning or abated by various groups since 1945.

Fire Name	Location	Year Completed	Lead Abatement Agency	Abatement Method	Present Status 1987
GOVERNMENT EXTINGUISHED					
Excavation (Including Trenching) 1980 - Present					
Larksville	Larksville	1985	BOM, OSMRE	Trench, excavate	Out
Maffett	Sugar Notch	1987	OSMRE	Excavate	Out
Archbald	Archbald	1986	OSMRE	Excavate	Out
Forestville	Forestville	1986	OSMRE	Excavate	Out
Hughestown	Hughestown	1984	OSMRE	Excavate	Out
Sugar Notch Outcrop	Sugar Notch	1984	OSMRE	Excavate	Out
Excavation (Including Trenching) 1945 - 1980					
Kulpmont	Kulpmont	1950	BOM	Trench	
		1958	PADER & County	Strip	
		1960	BOM	Excavate to mine pool level	Out
Mt. Carmel	Mt. Carmel	1950	BOM	Surface seal	
		1952	State & County	Surface seal	
		1967	PADER	Excavate	Out
Tower City	Tower City	1954	BOM & Owner	Excavate	Out
Cedar Avenue	Scranton	1953	BOM	Excavate	
		1965	BOM	Flush and excavate	
		1973	BOM	Excavate	Out
Throop	Throop	1968	BOM	Excavate	Out
Kehley Run	Shenandoah	1969	PADER & BOM	Excavate	Out
Hazleton	Hazleton	1969	BOM	Excavate	Out
Swoyersville	Swoyersville	1958	Collier	Unknown	Burning
		1973	BOM	Isolation trench	Out
Peach Mountain	Peach Mountain	1949	Federal	Direct attack	Out
Coal Run	Coal Township	1963	BOM & State	Trench and flush an isolation barrier	Out
Inundation					
Shenandoah	Shenandoah	1960'S	BOM	None	Controlled, isolated by mine pool and natural barriers
Surface Sealing					
Shamokin	Shamokin	1951	BOM & County	Surface seal	Out
Blind Flushing					
Eddy Creek	Dickson City	1974	BOM	Blind flush with crushed breaker refuse	Controlled
North Scranton	Scranton	1960	BOM & PADER	Blind flush with sand	Controlled
Eynon Street	Scranton	1965	BOM, PADER	Blind flush with sand	Controlled
EXTINGUISHED BY MINING COMPANY					
Direct Attack/Excavate/Trench					
Gilberton	Gilberton	1930'S	Collier	Inundate and backfill	
		1950'S	Collier	Strip and backfill a barrier	Controlled
Jersey	Avondale	1960'S	Collier	Direct attack	Out
Continental	Taylor	1950'S	Collier	Direct attack	Out
Loomis	Wilkes-Barre	1960'S	Collier	Direct attack	Out
Packer #5	Girardville	Pre-1964	Adjacent Colliers	Stripping	Controlled, strippings have isolated the fire area
Inundate					
Lansford #4	Lansford	1964	Collier	Inundation by mine pool	Out
Primrose	Mahanoy City	1962	Collier	Inundation by mine pool	Out
Susquehanna #8	Wilkes-Barre	1950'S	Collier	Inundation by mine pool	Out

Table 1.--Current status of 50 underground anthracite mine fires currently burning or abated by various groups since 1945.

Fire Name	Location	Year Completed	Lead Abatement Agency	Abatement Method	Present Status 1987
			Surface Sealing		
Williamstown	Williamstown	1964	Collier	Surface seal (Plug in portal)	Controlled
			Blind Flushing		
Rahn #11	Tamaqua	Pre-1964	Collier	Place water to extinguish	
		1969	Collier	Blind flush with sand	Controlled
			NO SURFACE EVIDENCE		
Wadasville	St. Clair	Pre-1968	Collier		Out
Pine Hill	Minersville	Pre-1968	Collier (Presumed)		Out
Humbert	Archbald	Pre-1970	Collier		Presumed out, no surface evidence of active burn
			BURNING UNCONTROLLED		
Coaldale	Coaldale	1983			Burning
Bear Valley	Zerbe Township		PADER		Burning (Preliminary analysis, fire is isolated)
Top Ross Outcrop.	Sugar Notch				Burning
Forestville	Forestville	Active	PADER		Burning
Carbondale	Carbondale	1950	BOM & DER	Flushing silt	
		1974	BOM & DER	Excavation	
		1986	OSMRE		Burning (Preliminary analysis fire is isolated)
Wanamie-Glen Lyon	Hanover	1960'S	Collier	Underground seals	Burning
Locust Gap	Locust Gap	1930	Collier	Direct attack	Burning
Centralia	Centralia	1966	BOM	Excavate	Most citizens relocated, burning
		1974	OSMRE	Flush a flyash barrier and excavate	
		1978		Reinforce barrier	
		1983		Diagnostic drilling	
Warrior Run	Warrior Run	1971	BOM	Combination-flushing and excavation	Burning
Summit Hill	Summit Hill	Pre-1950	Collier	Flush with silt, place water to extinguish	Burning
Laurel Run	Georgetown	1971	BOM	Trench and flush a sand barrier	Burning
Lansford #9	Lansford	Pre-1964	Collier	Place water to extinguish	Burning
Potts Colliery	Locustdale	1959	Collier	Place water at fire zone to extinguish	Burning
			ABATEMENT IN PROGRESS (DER)		
Maysville	Maysville	Active	PADER	Trench, excavate	Under contract for extinguishment
Truesdale	Hanover Township	1928	Collier	Underground seals	
		1950'S & 1960'S	Collier	Underground seals and backfilling	
		Active	PADER	Trench and excavate	Under contract for extinguishment
Glen Burn	Glen Burn	Active	PADER		Under study

occurred when pumps in the mines were shut off. One fire (Williamstown) was abated by surface sealing and another fire (Rahn #11) was controlled by blind flushing with sand. The other five successful efforts were by direct attack or underground sealing.

The 20 fires fought successfully by government agencies include 15 excavation operations, one combination inundation/natural barrier operation (Shenandoah), one surface sealing operation (Shamokin), and three flushing operations (Eynon Street, North Scranton, and Eddy Creek). Seven of the 33 fires (Eynon Street, North Scranton, Eddy Creek, Rahn #11, Bear Valley, Gilberton, and Packer #5) have been controlled by confining, isolating, or preventing fire spread to inhabited areas. Each of these fires is still burning or may reignite.

The 17 fires which have not been controlled include two currently being abated by excavation techniques (Truesdale and Maysville), one which is under study and was formerly considered isolated (Glen Burn), and 14 which are burning uncontrolled, typically in areas where effects on people are not expected. The burning uncontrolled fires are, however, on the DER Inventory of fires to be abated.

ABATEMENT TECHNIQUES

As noted by McElroy (1938) and Chaiken et al. (1983), the private colliers' preferred method of eliminating a mine fire was by direct attack, using an appropriate excavation technique (i.e. mechanical mucking or hand shoveling and loading) to remove and isolate the hot material, and using available water for quenching. An alternate choice was construction of seals to starve the fire of oxygen and reduce the intensity of the fire to a point where it could be excavated. Another alternative was to install barriers to retard fire spread, usually by blind flushing of non-combustible material through boreholes drilled into abandoned workings. At some fires multiple abatement activities (e.g. flushing, followed by excavation) were undertaken, often because the first method employed did not work. Some fires are still burning despite multiple abatement attempts (table 1).

The widespread abandonment of underground mines in the anthracite coalfields has severely restricted access to underground fire sites. Because of the limited access, certain abatement techniques and combinations of techniques have evolved. The most common abatement techniques are excavation, inundation, flushing, and surface sealing.

Excavation

As shown in table 1, excavation (with associated quenching of hot material) was the preferred method of government-funded abatement for underground anthracite fires between 1945 and the present. (For the purpose of this work, trenching has been considered a type of excavation.) Chaiken et al. (1983) showed that excavation was 80% successful in the elimination of underground anthracite fires versus a success rate of approximately 50% for blind flushing and/or barrier construction, and even less for inundation and surface sealing. However, the recent finding that a remnant of the Carbondale fire exists, coupled with the spread of the trenched and flushed fire at Coal Run, reduces the reported excavation success rate to 60%. From the data summarized here, the excavation technique has been successful in 15 of 19 mine fire abatement projects conducted between 1960 and the present. Of the four unsuccessful excavation projects (table 3), three were combination excavation/flushing projects (Warrior Run, 1971; Centralia, 1966 and 1974; and Coal Run, 1963). It should also be noted that although initial excavation phases at Cedar Avenue in 1953 and 1965, (Dierks et al. 1971) and Kulpmont in 1950 were initially unsuccessful, the excavation technique was later successfully applied at both sites. We believe that in two unsuccessful excavation/flushing project cases (Warrior Run and Centralia) the fire breached the flushed barriers which had been installed. At Coal Run, fire advance has been checked in the direction of an installed trench but has spread in another direction. The fourth excavation project which was unsuccessful is Carbondale. OSMRE is currently monitoring to delineate the location and extent of the fire underground. Results of the study indicate that the fire was not completely excavated. However, at present the fire is confined within barriers caused by natural and manmade underground conditions, and indications are that the fire will burn itself out without causing significant damage to people or the environment.

Table 3.--Costs of unsuccessful attempts to extinguish mine fires by excavation, by government agencies, 1945 to present.

Fire Name	Surface Area (Acres)	Cubic Yards Excavated (Thous.)	Cost (Thous.)
Carbondale	250		6,750
Warrior Run	18	58	732
Centralia	300		3,900
Coal Run	100		197

Since 1980, both OSMRE and the DER have exclusively relied on the excavation technique; six underground fires have been excavated by OSMRE and all have been successfully extinguished. The DER is currently eliminating two extensive underground fires (Maysville and Truesdale) by the isolation trench and excavation method. It also should be noted that all current OSMRE anthracite refuse bank fire abatement work is accomplished by excavation.

The most notable drawback to the excavation abatement method is cost. As shown in table 2, costs of excavation are substantial, typically into millions of dollars. The exceptions to these high costs are fires which are rapidly excavated when the fire is first discovered (e.g. Maffett and Archbald).

Table 2.--Costs of mine fires successfully excavated by government agencies, 1945 to present.

Fire Name	Surface Area (Acres)	Cubic Yards Excavated (Thous.)	Cost ($Thous.)
Larksville	10	2,000	8,300
Maffett	2	15	215
Archbald	8	166	425
Forestville	4	340	900
Hughestown	4	166	608
Kehley Run	30 Est.	5,400 Est.	11,700
Hazleton	8	845	1,445
Swoyersville	8	932	797
Throop	7	420	762
Kulpmont	30		180
Mt. Carmel	170		8268
Tower City	6		241
Cedar Avenue	34	2,500 EST.	5504
Sugar Notch Outcrop	1	4,000	28
Peach Mountain*			

*Griffith et al. (1960)--No details given

Sealing

Surface sealing was implemented on three fires (table 1). The seals applied at the Williamstown and Shamokin fires have been successful; however two efforts at sealing the Mt. Carmel fire were ineffective, and the fire was later excavated (table 1). The Williamstown and Shamokin fires involved relatively small surface areas (1-7 acres), whereas the Mt. Carmel fire involved 170 acres. The use of surface sealing as an abatement technique in the anthracite measures has been and is considered to be an ineffective method largely because of the effects of subsidence, which severely reduce seal effectiveness (McElroy 1938; Chaiken et al. 1983).

Inundation

The inundation abatement method has been effective in four of nine cases (table 1). Inundation by the "natural" rise of the mine pool (when pumping of water from the mines is stopped) has been the prime method of success, accounting for three of the four abated fires (Susquehanna #8, Lansford #4, and Primrose). Passing water over or concentrating water on fire-affected and burning materials has not proven to be an effective technique. The low conductivity of the coal and surrounding strata, the relatively short length of time the water is applied, and the naturally pitched mining horizons which limit the amount of workings which can be inundated, contribute to the ineffectiveness of the technique. It is also evident that fires burn at the top of the workings and may "burn" in the rock strata above the mine workings, perhaps in the gases volatilized from the coal.

A combination flushing/inundation technique has proven effective in only three cases out of nine attempts (table 1). It is our conclusion that the flush barriers do not provide a tight enough seals to contain water in the target area. Further fire tends to concentrate along the coal ribs, near the roof, and in higher elevations of the mine; those areas underground which are least likely to be inundated for the period of time required to extinguish the fire.

Flushing

Based on the available mine fire information, blind flushing is about 50% effective as an abatement or control technique; 12 cases of blind flushing were found (table 1), and five seem to be successful. McElroy (1938) reported a 50% success rate on abatement work prior to 1936. Chaiken et al. (1983) reported the same on abatement work prior to 1979. The inaccessibility of the workings and caved underground conditions are the main obstacles to success of the blind flushing technique (McElroy 1938). Further, it is likely that the flushing materials used do not provide a tight enough seal to preclude oxygenation of the fire area.

However, it must be noted that blind flushing with sand has proven successful in three of the five fires controlled by the blind flushing technique. The reasons for this success rate are speculative, but sand is heavier and differently shaped than other flush barrier media (coal refuse and flyash), and consequently packs tighter and consolidates less over time. It should also be noted that in two of the three successful blind flushing projects using sand (Eynon Street, 1965; North Scranton, 1960), relatively flat workings were present. We believe that flushing will not be successful in controlling a fire in steeply pitching areas because the material will flow to the low points and not form a barrier.

FUTURE OCCURRENCES

A minimum total of 12 fires were controlled or abated by government and industry in the period between 1945 and 1960 (table 1). In 1962 there were 23 fires burning out of control. By 1968, 25 fires were burning out of control, with nine carried over from the 1962 survey. In 1979, BOM files listed 12 underground fires actively burning in abandoned anthracite mine workings. The list included five carried over from the 1968 record. In the intervening nine years (1979 through 1987), two fires (Carbondale, 1974; Laurel Run, 1971) listed as abated or controlled in 1979 have reignited or are still burning, and seven new fires were abated or controlled. Based on these available data, it is estimated that one or two additional underground fires per year will occur in the anthracite fields.

Although the origin of each fire is difficult to pinpoint, a survey of project files indicates that approximately 70% of the fires whose origin is mentioned, were started in strip pits or bank areas where illegal dumping had occurred. The occurrence of illegal dumping in the anthracite fields is expected to increase because of the availability, location, and number of unreclaimed strip pits; the increasing cost of trash disposal; and the recent closings of numerous landfills in the area.

SUMMARY

Since 1945 a total of 50 underground mine fires in the anthracite coalfields of Pennsylvania have been discovered, and 33 of these have been abated or controlled. Government agencies (BOM, OSMRE, DER) have conducted work at 26 of the listed mine fire sites and have been successful at 20 sites. Private colliers have attempted to abate 22 of the listed sites and were successful in 13 attempts. A total of 17 underground mine fires are known to be burning at present, three of which are undergoing abatement work by DER.

The most successful abatement technique is excavation or a form of excavation. Excavation has been successful in over 70% (15 of 21) of its applications, and is likely to be unsuccessful only when excavation is not complete. However, because of the inaccessibility of the mine workings and the need to remove overburden, excavation is probably the most expensive abatement technique.

The high costs involved in the excavation or a modified excavation technique have led to the use of other abatement methods such as flushing, inundation, and surface sealing. Success rates for the other abatement methods are below 50%. The main obstacles to the success of the other abatement techniques are natural phenomena such as the occurrence and extent of subsidence and local geology. Consequently, to assure that the fire is extinguished the excavation technique is the method of choice in abating underground mine fires.

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BURNOUT CONTROL AT THE ALBRIGHT COAL WASTE PILE FIRE[1]

Robert F. Chaiken and Larry G. Bayles[2]

Abstract.--A novel technique for the control of fires in coal waste piles has been developed and tested by the Bureau of Mines. It is an important step in developing a comprehensive approach to solving the technical, environmental, social, and economic problems associated with fires on abandoned coal-mined lands. In the Burnout Control process, a pipe is inserted into the waste pile, and a large suction fan applies a vacuum to the interior of the pile causing ambient air to flow into the pile. The air flows through the porous waste and into the interior fire zones thereby enhancing the burning process. All heat and fumes produced are collected and exhausted through the suction pipe and fan. Burnout Control was tested in a 0.75 acre zone of a 300,000-yd^3 burning coal waste pile near Albright, WV. In this first trial, there was no intent to utilize the heat produced, but simply to test the applicability of the Burnout Control concept to a burning waste bank. Preliminary interpretation of the data indicates that Burnout Control is indeed applicable to burning coal waste fires, and that it can function in an environmentally and economically sound manner.

INTRODUCTION

The Bureau of Mines for several years has been developing an in situ combustion concept and technology called 'Burnout Control' which can be applied to the control of fires in underground coal mines and in coal refuse piles (Chaiken 1980, 1983; Kim et al. 1984). There are several important aspects related to Burnout Control which can become part of a comprehensive approach to solving the technical, environmental, social, and economic problems associated with abandoned coal-mined lands. First, is the extinguishment of the fire by burning the fuel to completion with control of all the heat and fumes produced. Second, is the potential utilization of the heat of combustion for production of electricity. Third, is the production of nonacid-producing coal slag products (red dog) which can fill mine voids and/or be used as a gravel substitute. Fourth, is the possible revenues from sale of heat and electrical energy and ash products which could offset the entire cost of individual reclamation projects. It is believed that this latter aspect - that is, reclamation in which costs are offset through utilization of waste - is essential if a major impact is to be made on the nations' Abandoned Mined Lands problems. This is because that the more conventional reclamation techniques would require the unrecoverable expenditure of many billions of tax dollars.

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[1] Paper presented at the 1988 Mine Drainage and Surface Mine Reclamation Conference sponsored by the American Society for Surface Mining and Reclamation and the U.S. Department of the Interior (Bureau of Mines and Office of Surface Mining Reclamation and Enforcement), April 17-22, 1988, Pittsburgh, PA.

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At this time, significant progress has been made in developing a Burnout Control system by demonstrating its operation in field trials at a burning abandoned coal mine and a burning abandoned coal waste bank. The Calamity Hollow Mine Fire Project, which was carried out at an underground mine in 1982, has been previously reported in detail (Irani et al. 1983; Dalverny et al. 1984; Chaiken et al. 1984, 1987; Soroka et al. 1986). The field trial at the Albright Waste Bank Fire Project (Chaiken 1987) has been completed only recently, and this paper presents a preliminary report on that work. Detailed reports must await completion of the analyses of the approximatly 150,000 data points and 200 pages of written notes taken during the field operation.

BURNOUT CONTROL PROCESS

Burnout Control, is a method for burning coal wastes in situ involving exhaust ventilation through a pipe inserted into the pile with the amount of suction achievable with available fan systems. Maintaining the waste pile at negative pressure relative to atmospheric induces airflow through the surface of the pile and into the buried fire zones, while at the same time exhausting product heat and fumes through the fan. In essence, the process is like smoking a pipe of tobacco with one long continuous draw. The improved aeration of the pile is expected to lead to a faster and more complete combustion process. If necessary, flue gas scrubbing could be used to further clean the gases prior to exhausting them to the atmosphere. The thermal energy of the hot flue gases could be used in a conventional boiler or other heat exchanger prior to exhausting to the gases.

ALBRIGHT COAL WASTE BANK FIRE PROJECT[3]

Waste Bank Site

Figure 1 is a diagram of the Burnout Control system initially designed for the burning coal waste bank near the town of Albright, WV. The site itself is situated along the west bank of the Cheat River about 1 mi north of the town and directly across the river from the village of Ruthbelle. The waste pile (approximately 1700-ft long, 200-ft wide, 40-ft high) contains about 300,000 yd^3 of coal waste with fly-ash and other refuse typical of older dump sites in the bituminous mining region mixed in. Samples taken at different depths from seven cased boreholes located over a top surface area of 0.75 acre (the planned fire zone) indicated the waste to have an elemental composition corresponding to $CH_{1.033}O_{0.200}N_{0.013}S_{0.024}(ASH)_{0.33}$ with an average heating value of 5,800 Btu/lb or 50% of that of bituminous coal. Permeability tests made by exhausting air from the same seven boreholes, indicated an air permeability which generally decreased with depth, having an average value of about 200 D (or 20% of that of dry sand) near the base of the pile. Porous flow calculations (see Chaiken 1987) indicated that this permeability would support a 6,600 std.ft^3/min exhaust flow with a 5-ft diameter pipe at a vacuum level of 55 in H_2O. At an expected gas temperature of 1,750° F, the exhaust would correspond to a thermal output of 5 MW which could convert to 1 to 1.25 MW of electrical power. During the Albright field trial, no effort was made to utilize the thermal power generated.

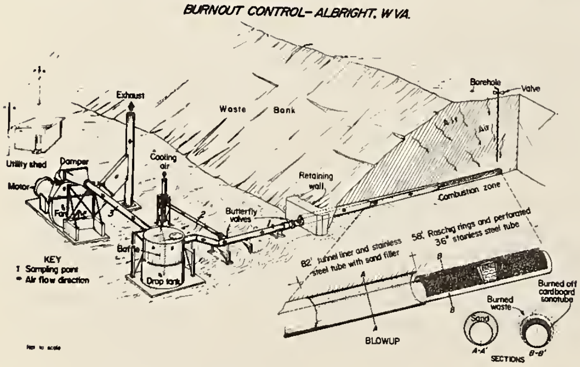

Fig. 1. Artist Rendition of Burnout Control System at Albright, WV.

Burnout Control System Design

Configuration of the burnout control system (Green International Inc. 1986) is shown in figures 1 and 2. The combustion manifold inserted into the bank was a 3/16 inch wall duct of 309 stainless steel, 138 ft long and 3 ft in diameter. The last 10 feet of the manifold tube consisted of a half-round section surrounded by a 48-inch cardboard sonotube filled with rashing rings and charcoal to assist in obtaining an initial uniform fire zone. Forty feet of the duct was perforated with about 300 2 1/2" holes and surrounded by a web thickness of up to 1.0 ft of 3-in refractory rashing rings held in place by the sonotube, which would burn away to result in a 4-ft-diameter, 50-ft-long, essentially uniform vacuum zone inside the pile into which combustion products would be drawn. A 5-ft-diameter steel tunnel liner, which served as a construction tool for inserting the combustion manifold, surrounded the unperforated length of the manifold. The annular space between the tunnel liner and the combustion manifold was filled with sand and stopped with a steel barrier constructed at a point where both ducts emerged from the pile. The combustion manifold outside the bank was connected to the fan through an expansion joint, a main shut-off valve, additional ducting, and a drop-out tank to remove any large particles from the exhaust. In this first field trial, there was no intent to utilize the heat produced, therefore the exhaust gases were simply emitted to the atmosphere after they were cooled by dilution with cold air which was drawn into the hot exhaust duct at a point before the drop-out tank (fig. 1, 2). However, the system design did allow for retrofit of an air pollution control system, if needed. As will be described in the next section, an alkali wet scrubber was eventually installed to control the exhaust emissions.

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[3] The assistance of Patriot Coal Co., Morgantown, WV, and the WV Department of Energy in making possible the use of the Albright site is gratefully acknowledged.

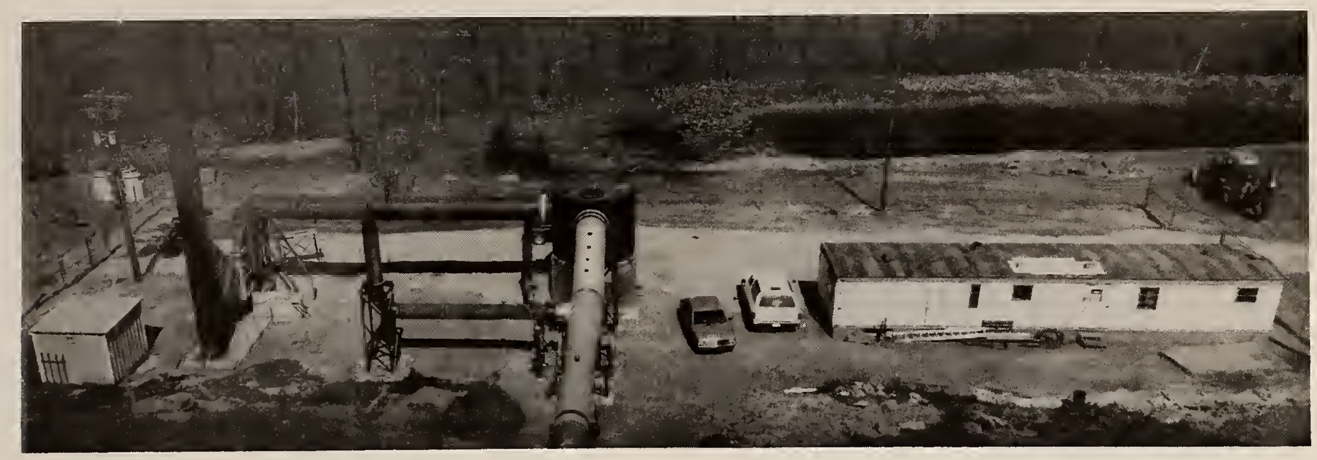

Fig. 2. View of Burnout Control System from Top of Coal Waste Bank.
(prior to installation of alkali wet scrubber)

An 8-in-diameter auxillary air inlet pipe was installed from the top of the pile to a point near the rashing rings (fig. 1). This pipe was to supply additional air for several possible purposes: 1) For igniting the waste immediately surrounding the manifold; 2) for cooling the combustion manifold if gas temperatures exceeded the working limit (1,800° F) of the 309 stainless steel; and 3) for afterburning the hot exhaust, if the gas mixture was fuel rich. As it turned out, this auxillary air pipe never functioned properly, to the detriment of the third purpose, which during the burnout operations became most important. A new auxillary air pipe eventually had to be installed from the backside of the waste pile (not shown in fig. 1 or 2). The exhaust fan was a centrifugal type, 1,700 rpm blower with corrosion resistant blades. Powered by a 400-hp, 2,300-V drive motor, it was designed to pull 40,000 std.ft^3/min. at 600° F, while maintaining a 50-in H_2O pressure drop. The extra capacity of the fan (20,000 scfm) was required to handle the dilution air used for cooling the exhaust.

The vacuum applied to the waste bank could be controlled by altering the position of the cold air inlet valve on the dilution air duct (in parallel with the manifold), and/or varying the damper opening to the fan inlet. It was also possible to completely stop the main flow from the combustion manifold at any time by closing the 36-in butterfly valve just downstream of the expansion joint and adjusting the vacuum at that point to zero. This was done routinely on numerous occasions during the burnout operations.

Instrumentation (direct reading and/or online for remote sensing and recording) was available to monitor pressures, flows, temperatures, valve positions, motor condition, and gas composition. A primary online instrument station (station #1) was located at the manifold where the high temperature exhaust exited the waste bank. Another online station (station #3), located in the duct leading to the fan inlet from the drop-out tank, yielded data on the cooled exhaust emitted to the atmosphere.

Burnout Control Operations

Around-the-clock operation of Burnout Control began in May 1986 and continued into the following months with the testing of equipment, instruments, and procedures. During this period, considerable burning took place in the waste around the combustion manifold which apparently had ignited spontaneously; however, the burning took place mostly under conditions of inadequate oxygen and exhaust temperature. Despite thermal outputs as high as 2.5 MW and exhaust temperatures as high as 450° C, low levels of oxygen prevented the complete combustion of the fuel gases present in the exhaust. The failure of the auxillary air pipe to function properly contributed to the problem of a fuel rich stoichiometry. Under these conditions, the stack emissions contained low levels of odoriferous H_2S and unburnt hydrocarbons which in turn led to complaints from nearby residents. Fan operations were temporarily shutdown in order to install a flue gas scrubber for eliminating the nuisance odors, which occur only under the conditions of poor reaction stoichiometry.

A wet scrubber system based on a spray of sodium hydroxide solution was designed and built into the drop-out tank. In addition, a 5 MW capacity tube-in-shell hot water heat exchanger was installed in the duct leading to the drop-out tank. The heat exchanger was necessary in order to dissipate a major portion of the sensible heat of the exhaust prior to contact with the sodium hydroxide spray solution to prevent excessive evaporation of the solution. The modified Burnout Control system was startedup again in September and operated mostly intermittently due to a number of reasons: 1) The need to winterize the site; 2) the need for parts replacement and maintenance related to corrosion induced by the scrubber system; and 3) the need to insert a new auxiliary air inlet pipe into the waste bank for achieving an increase of oxygen into the hot manifold exhaust for more complete and cleaner combustion.

By January 1987, clean burning conditions were achieved, and through March 1987 it was possible to produce controlled thermal outputs of up to 5 MW and temperatures as high as 930° C (1,700° F)- the original maximum design level. It was observed that with exhaust temperatures exceeding 600° C (1,100° F) and oxygen levels exceeding 0.5 to 1.0% in the exhaust, all nuisance odors disappeared. Carbon monoxide in the exhaust was generally 140 to 200 ppm indicating essentially complete combustion, and sulfur dioxide stack emissions were only 200 to 400 ppm within air pollution requirements for the local area.

During an elevated vacuum test in March 1987, the temperature of the stainless steel duct inside the waste pile apparently exceeded its maximum working temperature (980° C or 1,800° F) for useful wall strength. Thus the 36-in diameter stainless steel pipe was sucked closed at a point about 30 ft into the pile, which terminated the field trial.

Output Data

Figures 3 to 8 depict some data-time plots encompassing the last 5 days of the field trial[4]. Figure 3 shows the vacuum level at station #1 on the combustion manifold which was varied from 25 to 50 in H_2O. The increase in vacuum after day 1 was an attempt to compensate for the observed decrease in flow (fig. 5). Normally, the vacuum and flow at station #1 follow each other quite closely. At the time however, the operator did not realize the decrease in flow was due to the collapsing combustion manifold. The exhaust temperature at this time (fig. 4) was at its measured peak of 930° C (1,700° F), with a corresponding thermal output of 5 MW (fig. 6). Even after collapse of the manifold, sufficient hot gas was exhausted to yield a thermal power level between 2 and 3 MW.

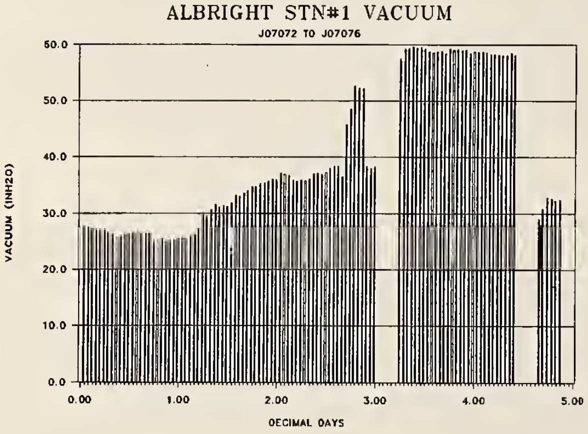

Fig. 3. Applied Vacuum at Station #1.

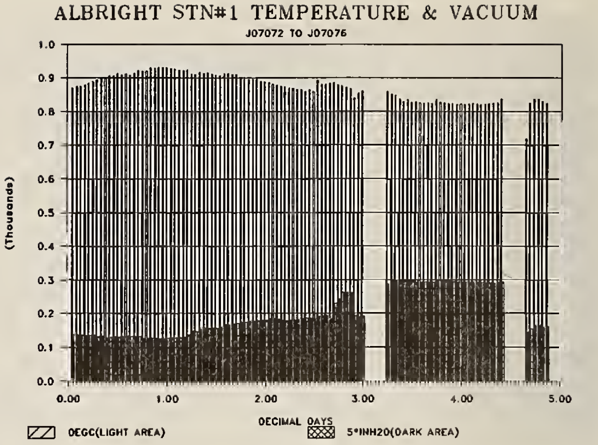

Fig. 4. Exhaust Gas Temperature at Station #1.

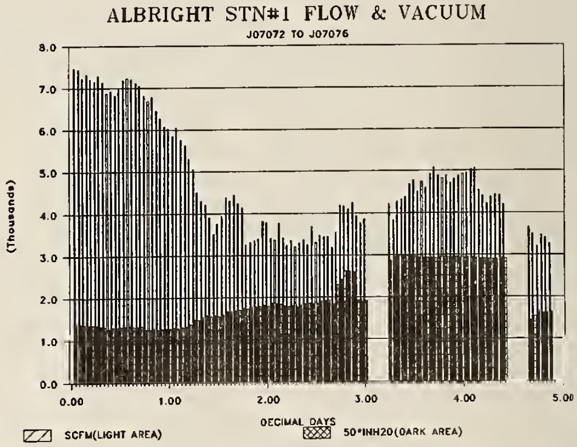

Fig. 5. Exhaust Gas Flow at Station #1.

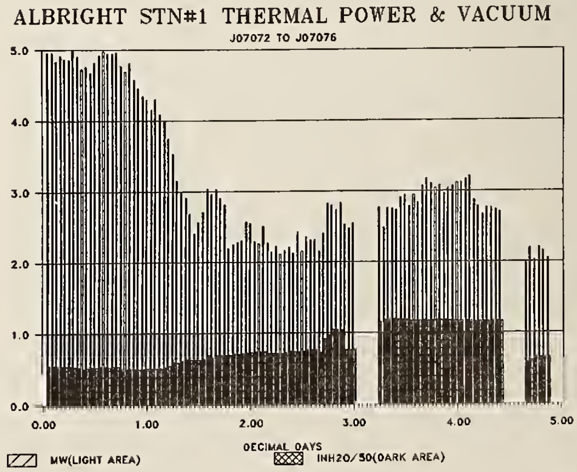

Fig. 6. Thermal Power Level of Exhaust at Station #1.

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[4] The absence of data for part of the time in figures 3 to 8 is due to the fact that either the fan was turned off or the appropriate instrumentation was not functioning at the time.

Figure 7 shows the effective energy gain by the Burnout Control process during the last 5 days of operation. This gain is essentially the amount of energy produced by burning relative to the amount of energy consumed by operation of the Burnout Control system. It is given here as the ratio of exhaust thermal power to fan motor consumption power after correcting for the amount of fan power used to pull in cooling dilution air and water vapor. Because the fan uses most of the electricity consumed during Burnout Control operations, the energy gain factor is a good indication of the economical viability of the process. The observed gains shown in figure 7 are about a factor of 50, and consistent with previous predictions (Chaiken 1980, 1987).

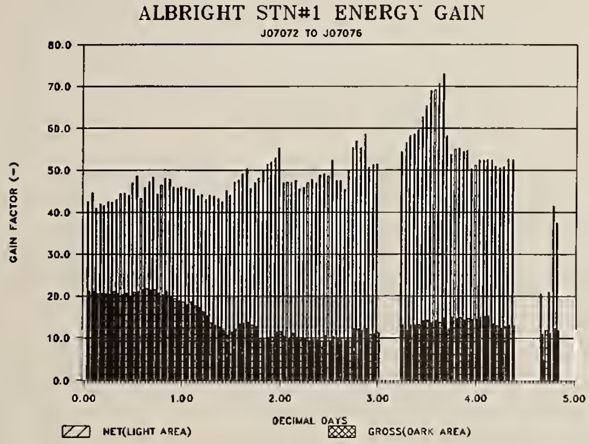

Fig. 7. Energy Gain Factor in Exhaust Gas at Station #1.

Figure 8 depicts the 5-day time plot of SOx emissions as determined from on-line gas sampling from the duct leading to the fan, i.e., after scrubbing. The levels of SOx shown here (140 to 240 ppm) are relatively small and probably acceptable in this locale. Future process designs may well have more efficient SO_x scrubbers that could reduce the SO_x emissions to even lower levels.

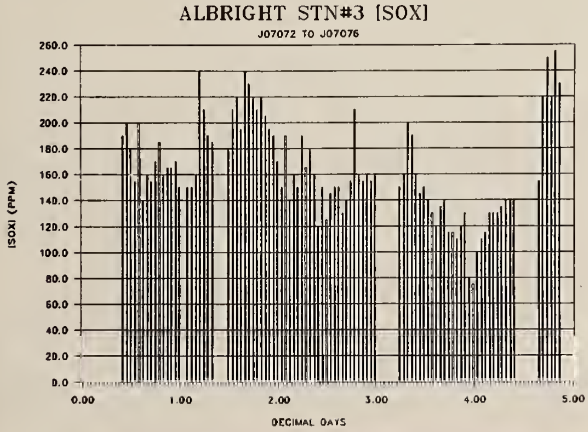

Fig. 8. SOX Emissions to Atmosphere. (measured at Station #3)

CONCLUSIONS

Work is still underway to analyse in detail the data and observations accumulated over the 1 year of the field trial at Albright. Meanwhile several significant results are already apparent:

1. The basic Burnout Control process is applicable to burning coal waste piles. An estimated 2,000 tons of waste were consumed during the trial.

2. Designed output levels of hot gas flow, temperature, and gas composition were achieved; however there are needed improvements in engineering design, especially for the khigh-temperature exhaust manifold and the exhaust gas scrubber.

3. Essential data were provided on what process controls are needed for optimum output.

4. Essential experience was obtained on controlling emissions and moderating flows.

Further data analyses are expected to reveal additional useful results - particularly on the propagation of the combustion zone within the bank, and the treatment and control of subsidence. Although this information is still forthcoming, it is clear that the work at Albright has already brought us a big step forward in establishing a viable means for controlling AML coal fires, and for converting smoldering coal wastes to an energy resource.

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HEAT REMOVAL METHODS FOR CONTROL OF UNDERGROUND ABANDONED COAL MINE FIRES

Louis E. Dalverny

Abstract.--The Bureau of Mines is conducting research to determine the effectiveness of several related techniques for the removal of heat from underground fires in abandoned coal mines. Mine fires are notoriously difficult and dangerous to extinguish because the heat becomes deeply seated in the coal and in the surrounding rock strata, and there can be potentially explosive gases near the heated material. Fire control methods which attempt to deprive the combustion zone of oxygen are ineffective, as the fuel can smolder indefinitely at <2 pct oxygen concentrations. Methods that excavate the coal seam produce extensive and expensive surface disruption affecting the landscape and surface structures. The Bureau has developed heat removal methods to remotely extract thermal energy from the underground fuel and adjacent heated rock strata. The mine then cools below the temperature needed to sustain combustion and negative effects on the surface are minimized. The Bureau techniques draw heated underground gases to the surface with an exhaust fan attached to a borehole into the mine. Water, detergent foams, or cryogenically liquified inert gases injected into the mine can enhance the energy-absorbing capacity of the subsurface gases. Two completed field trials have used water, injected as a spray or in a stream. A current project will use one or more foams to carry water and other chemicals to the burning material. Future activities may use cryogenic gases to both cool directly and remove heat indirectly via the exhaust fan.

INTRODUCTION

Small fires that occur at, or near, an outcrop of coal, if unnoticed or ignored, can become deeply seated fires in abandoned underground coal mines. The old mine usually is too dangerous to enter, so fire-fighting must be done from the surface. One option is careful and total excavation, with the attendant disruptions to the environment in the vicinity of the mine. The excavator must contend with hot, flammable material and potentially explosive gases. Another conventional technique attempts oxygen deprivation by surface sealing. This goal is difficult to attain because of the many pathways for air to enter the workings; the seal is practically impossible to maintain over the long periods of time necessary for cooling of fuel and rock to below self-heating temperatures of 40 - 70° C (104 - 158° F) as obtained in laboratory studies of spontaneous combustion susceptibility of Pittsburgh seam and other coals (Kuchta et al. 1980, Smith and Lazzara 1987).

Bureau of Mines research into remote fighting of fires in abandoned underground coal mines has focused on removing the thermal energy from the

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[1] Paper presented at the 1988 Mine Drainage and Surface Mine Reclamation Conference sponsored by the American Society for Surface Mining and Reclamation and the U.S. Department of the Interior (Bureau of Mines and Office of the Surface Mining, Reclamation and Enforcement), April 17-22, 1988, Pittsburgh, PA.

[2] Dalverny is a Physicist, U.S. Department of the Interior, Bureau of Mines, Pittsburgh Research Center, Pittsburgh, PA.

combustion system. (Even in the total excavation method, the hot strata must be cooled before the materials can be stowed anywhere.) The basic problems are to find inexpensive substances with good heat-absorbing properties that can be conveyed easily into and through the subterranean environment and subsequently returned to the surface without damaging the surface environment. The research to date has identified some likely candidates and some positive and negative attributes associated with use of these materials to achieve mine fire extinction by remote means. This report briefly discusses recent field studies and summarizes the overall findings to date. Also described are new approaches to heat removal that are under consideration for field trial.

BASIS OF HEAT REMOVAL TECHNIQUES

In any fire situation, extinguishing the combustion can be accomplished by removing any of the three necessary components: oxygen, fuel, and thermal energy (heat). Oxygen deprivation by sealing the earth above a burning underground mine, even if there are no surface structures or other impediments, is difficult and expensive to implement and may not be successful. If the "sealed" mine is normally an active coal-producing one, methane often will desorb from the coal and displace most of the oxygen not consumed by the fire. Nonetheless, O_2 concentrations below 2 pct can sustain smoldering combustion (Smith and Lazzara 1987). Moreover, a fire in an abandoned coal mine is often ignited at the outcrop years after the mine has ceased operation, and after essentially all the methane has desorbed and been lost. Therefore, in a surface-sealed abandoned mine, only combustion products would be available to displace the air that had been drawn into the mine by convection currents created by the burning and by atmospheric pressure changes. Sealing the surface and the thousands of strata fractures is exceedingly difficult, especially where there are buildings on the surface or subsidence over the entries. With shallow mines, it is impossible in practice to sufficiently reduce the oxygen level in the air available to the carbonaceous fuel for the long time periods (5 - 10 yr) needed while the materials cool to below reignition temperature (40 - 70° C or 104 - 158° F). Injection of inert gas, as conventionally implemented to displace oxygen, also requires long time periods and expensive quantities of the gas to achieve cooling.

A second alternative for fire extinguishment is removal of the fuel. Fire extinguishment is certain if all the fuel is removed and treated correctly. However, this activity is expensive, causes extensive disruption of the surface terrain, and consequently has both concurrent and lasting environmental effects on the surrounding area. Hot material is dangerous to transport and must be cooled and mixed with incombustible material before it can be redeposited at the mine site or elsewhere. There is always the possibility of continued burning if total excavation is not done (Magnuson 1974).

Removal of the third constituent in the fire triangle, heat energy, is an extension of natural processes occurring in abandoned coal mines without fire. No burning will occur if (a) the thermal energy produced by natural oxidation and wetting is removed quickly enough to prevent energy storage leading to sustained, rapid exothermic reactions, and (b) there are no other external inputs of energy into the fuel. In theory, large quantities of ordinary air rapidly passed over the hot surfaces should remove the heat. In practice, it is difficult to sustain both high air volumes and high airspeeds through the rubble in collapsed mine entries. Forced flow of plain air generally accelerates combustion; this also can be considered as a method of removing fuel and is the basis of controlled burnout (Chaiken 1980).

The Bureau's heat removal concepts address these practical concerns by using air, which is an inexpensive, plentiful fluid, as a carrier for other substances that have larger heat capacities. In this context, it is necessary that the flow direction be controlled. This is accomplished by:

1. Use of an exhaust fan connected to the underground mine network through a cased borehole, and
2. Injection of cooling or heat-absorbing compounds into the subsurface flows induced by the fan's suction.

In these applications, the fan generates a vacuum which induces underground gas flow along the pressure gradient to the surface.

TESTING OF HEAT REMOVAL TECHNIQUES

The earliest use of a heat removal technique was at the conclusion of in situ combustion simulation experiments in a surface trench in which coal or coal wastes had been burning for several days (Chaiken et al. 1981). During the experiments, a fan drew air through the hot material to supply oxygen and sustain accelerated combustion under controlled conditions. At the end of the study and with the fan operating, water sprayed onto the top of the bed of carbonaceous material percolated down and quickly quenched the combustion reactions so that the bed could be dissected for analyses. The fan pulled any quantities of carbon monoxide, hydrogen, and other products of low-temperature combustion of coal generated during the cooling and quenching process through the bed into an incinerator. Maintaining a negative pressure on the fuel bed also reduced the possibility of explosions from concentrations of heated flammable gases.

FIELD TEST OF WATER INJECTION WITH FUME EXHAUSTION, CALAMITY HOLLOW

Based on successful application of the technique under laboratory conditions, a trial quenching was done at the end of the first field evaluation of the Bureau's Burnout Control technique at an abandoned underground coal mine at Calamity Hollow, PA. The Burnout Control process had produced exhaust gases with an average temperature of 600° C (1,112° F) for most of the 4-month activity. Burning had been extended to a radius of 36 - 42 m (120 - 140 ft) from the exhaust manifold. Excavation of the site was scheduled to furnish data about the effects of the controlled combustion on the mine entries and surrounding strata.

Prior to excavation, the heat removal process was tested at the site. To implement the quenching trial using the Water Injection with Fume Exhaustion (WIFE) technique, a water distribution network was connected to all the air inlet boreholes on the site. Streams of water saturated the hot material at the bottoms of the boreholes and generated steam in the process; the exhaust fan drew the steam and other hot gases out of the mine. The high heat capacity of the water and its energy absorption in the latent heat of vaporization during the phase change removed thermal energy from the fuel and lowered temperatures. Although water continued to be sprayed onto strata surfaces exposed during the excavation (as an extra safety precaution), the highest measured temperature in the solid materials upon exposure was about 150° C (302° F). It was estimated that about 50 pct of the burning carbonaceous material was extinguished during 30 days of water injection. By extrapolation from the data, total extinguishment might have occurred in about another 20 days (Chaiken et al. 1984).

FIELD TEST OF WATER INJECTION WITH FUME EXHAUSTION, RENTON, PA

A subsequent field study that attempted to extinguish combustion in several parts of another abandoned coal mine in southwestern Pennsylvania demonstrated some of the problems that can be encountered using this Water Injection with Fume Exhaustion (WIFE) technique. There were three thermally separate heated zones on the perimeter of the >24-ha (60-acre) site of another abandoned, turn-of-the-century mine in the Pittsburgh Coal Seam. The locations of the zones and the direction of movement of the combustion fronts had been determined by the Bureau's mine fire diagnostics technique (Chaiken 1984). As expected, no borehole was drilled into an actively burning area although some of the holes did become chimneys for hot gases that contained a lot of water vapor. Measured initial temperatures did not exceed about 80° C (176° F), but temperature is very deceptive because it is very localized (Kim 1986). Time-dependent monitoring indicated continuing significant combustion, however, and provided the information needed for placing additional boreholes to intercept the three combustion fronts.

A gravity-fed distribution system supplied water to the boreholes; there, the water was conveyed in small-diameter tubes to spray nozzles placed at the bottoms of the casings. Typically, the exhaust fans were operated about 6 h/day for 5 days/week with concurrent waterflow of about 0.04 - 0.06 L/S (0.6 - 1.0 gal/min) per borehole. The WIFE systems operated on the subsites for about 6 months including some hiatuses for data analyses and distribution system modifications.

Because there was concern that some of the borehole casing depth data were incorrect and that burning was occurring above the casing openings, the injection tubes were reinstalled outside the casings and about 0.30 - 0.61 m (1 - 2 ft) below the surface. The idea was to saturate the borehole surface so that any subsurface gases drawn through the wet strata would also become saturated with water vapor, and any fuel heating around the steel casing would be cooled by water flowing down the borehole surface. All boreholes served as the locations for temperature and pressure monitoring and gas sampling. Although some data indicated that thermal energy was being removed in the air and water vapor extracted by the fans, other data proved that combustion was being accelerated near some boreholes. The overall result was that general extinguishment did not occur. The probable cause was that insufficient quantities of water were carried by the induced airflows to all hot areas to overcome heat release by oxidation. The heated areas least likely to be exposed to adequate quantities of water (liquid or vapor) and most likely to be on fire would be in the roof strata. If the combustion is primarily in the carbonaceous roof strata and those strata are highly fractured, getting liquid water to those areas is particularly difficult due to the effects of agglomeration and gravity on the water flow. Without the latent heat of vaporization, air (with or without water vapor) may not absorb enough heat energy to counter the effects of enhanced oxygen availability when the fume exhaustion technique is applied. Discussion of these difficulties led to consideration of ways of enhancing the conveying of water to all parts of mine entries, whether collapsed or intact.

CURRENT RESEARCH USING FOAM INJECTION

As an outgrowth of the field tests using the Water Injection with Fume Exhaustion technique, current Bureau research is focused on development of a related heat removal technique using foam. Foams are, basically, large agglomerations of water films containing gases. Additives modify and strengthen the films so that foams having bubbles of specific size distributions can be formed and made to flow like a liquid or like a gas. As such, the use of foams for transporting water to heated zones in an underground mine fire may overcome the water flow problems observed at Renton. In concept, foams having different properties could be generated so as to:

(a) carry water to large void sections of mine entries, and to maintain those sections with a long-lasting supply of cooling water.
(b) fill small cracks and fissures in the roof area.

Contact between foam and heated fuel would cause the foam to break down structurally and deposit the water film on the solid surface where evaporative cooling and other reactions would occur.

Assuming the water were converted to steam, the increase in local gas pressure along with the injection pressure of the foam would move the steam elsewhere in the mine. A cooler downstream location would condense the steam and allow the thermal energy to be absorbed there; the effect could be to spread the heating farther into the mine. However, if in conjunction with foam injection, an exhaust fan appropriately located on the surface were put into operation, the suction would induce underground gas flows to a known vent. Additionally, the foam would be drawn along the same flow paths to maintain the heat removal from the entire flow network as the upstream segments cooled. As in operation of the WIFE system, continuing gas sampling and analysis would provide the necessary information about the progress of the extinguishment activity. The physical presence of foam, as with steam, would exclude oxygen, thus reducing the exothermic activity and slowing the rate of temperature increase.

Foam injection with fume exhaustion (FIFE) makes feasible the introduction of compounds other than water into the subsurface environment. The gas encapsulated in the water films can be an inert one, for example. The water additives that enable foam formation could be some that would coat the exposed carbonaceous surfaces and inhibit various chemical and biochemical reactions and processes. Evaluation of bactericides, such as some against Thiobacillus ferrooxidans which accelerates mine acid production, could be accomplished as a concurrent activity. In-mine application of bactericides is difficult to do for reasons including access to the workings and controlled release of the chemicals; much of the research has been done on surface coal and refuse piles (Erickson et al. 1985). Introduction of chemicals that retard surface oxidation may minimize the possibility of reignition while mitigating acid production. It could be possible to solve two environmental problems - fire effects and acid mine drainage.

Field testing of the FIFE technique is planned for the near future at another abandoned mine in the Pittsburgh Coal Seam, where the fire has been burning for at least 10 years. The two main objectives are:

1. Getting inexpensive water, with its especially high heat capacity (relative to gaseous N_2 or CO_2), to the heated fuel and adjacent rock; and
2. Extinguishing the combustion with minimal effects to the environment.

Again, the boreholes and the exhaust fan would be in place following the mine fire diagnostics necessary to delineate the combustion zones.

FUTURE RESEARCH USING CRYOGENIC FLUID

The advantages inherent in using an exhaust fan connected to a mine through a borehole within a set of instrumented holes have been proposed for use with an inert cryogenically liquified gas or gas mixture as the primary fire-suppressing and cooling medium. As with the foams, the cryogenic fluid would be injected into the underground network under pressure; at this stage, the fluid would be in the liquid phase so as to enhance its effective heat capacity. Upon exiting the bottom of the borehole casing, the liquid would vaporize as it absorbed thermal energy from the heated surroundings. While similar in this regard to water, the revaporized cryogenic fluid has a greater advantage over water for diluting or inerting the mine atmosphere to reduce the quantity of oxygen available for combustion reactions. The exhaust fan would draw the warmed gas out of the mine; there also would be additional cooling of heated surfaces downstream from the injection point. Balancing injected gas flow with exhaust fan flow should minimize influx of atmospheric air to the mine, thereby maximizing oxygen exclusion from the fuel.

In comparison to water, the usual inert cryogenic gases (nitrogen and carbon dioxide) have both smaller heat capacities and latent heat of evaporation effects during liquid to gas phase change, but the gases do not conduct thermal energy back to cooler surfaces as rapidly as does condensing steam. The very low initial temperatures of the gas vaporizing from the cryogenic liquid will cause a large temperature gradient that will promote thermal energy transfer. This alternative extinguishing system should have a minimal environmental impact and should be especially useful at abandoned mine fire locations that lack water. Combining an exhaust fan with the cryogenic fluid injection may increase the overall efficiency of the method so as to lower material costs that are normally quite high for conventional cryogenic fluid injection.

CONCLUSIONS

Three methods to effect removal of heat energy from fires in abandoned coal mines have been discussed. All involve using an exhaust fan to produce an underground pressure gradient that will cause heated gases and vapor to be drawn from the mine through a borehole connected to the fan. The other necessary component of the methods is the injection into the mine of substances that will (1) absorb thermal energy from the heated fuel, (2) move into all mine spaces (especially the carbonaceous roof strata) so as to make contact with all the fuel, (3) exclude as much oxygen as possible from the mine network, and (4) remain in the gas or vapor phase and flow to the outside atmosphere via the exhaust fan.

Plain water works quite well as a cooling medium, and particularly so when the injection boreholes are placed directly into burning material. Large heat capacity, latent heat of vaporization energy absorption, low cost, and general availability are its positive attributes for fire extinguishing. Its deficiencies in this application are that any steam generated can condense and release its absorbed energy to a cooler location, and the liquid phase coalesces and collects by gravity, flowing away to the floor of the mine.

Foams can carry water to all parts of the underground environment when the foams are properly formulated and injected. Similarly, cryogenically cooled inert gases will flow to the heated fuel and rock strata surfaces to absorb thermal energy and then be removed without transferring that energy to previously unaffected portions of the mine. Both foams and inert gases can exclude oxygen or dilute its concentration in the mine workings so as to reduce the rate of exothermic reactions and decrease the overall temperature. These methods are intended to be implemented with a minimal disruption to the surface environment, thereby reducing project costs.

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MINE FIRE DIAGNOSTICS TO LOCATE AND MONITOR ABANDONED MINE FIRES[1]

Thomas R. Justin and Ann G. Kim[2]

Abstract.--Locating a fire in an abandoned underground coal mine or waste bank is difficult using currently available methods. The Bureau of Mines is developing a mine fire diagnostic methodology to locate and monitor such fires. The method is based upon two assumptions: (1) that measurable changes in the emission of low molecular weight hydrocarbons from coal occur as a direct result of changes in temperature, and (2) that controlling the direction of the underground gas flow between borehole sampling points provides the means for locating the source of these hydrocarbons. This mine fire diagnostic method has been applied at three field sites. It was used to define combustion zones at an abandoned underground bituminous mine at Renton, PA. At this 60-acre site, which showed several areas of venting, the technique was used to delineate three noncontiguous combustion areas totaling approximately 10 acres. It was also used to follow the progress of the extinguishment effort. At Carbondale, PA, the method was used to locate heated areas in an abandoned anthracite mine. In this test, changes in the concentration of methane during communication testing were used as the combustion indicator. The mine fire diagnostic method is currently being used to define the combustion area at an abandoned bituminous mine in Large, PA.

INTRODUCTION

Fires in abandoned coal mines and waste banks are a relatively common occurrence. Surveys taken at least 10 years ago listed 292 waste bank fires and 261 underground fires in the United States (Johnson and Miller 1978, McNay 1971). In a study of problems associated with anthracite fires (Chaiken et al. 1983), it was noted that fire control efforts are expensive and that the success rate for fire control projects is low. In many cases, high cost and low efficiency are related to the inability to accurately determine the location and extent of fire in an abandoned mine.

The methods currently used to locate and assess underground mine fires have significant shortcomings. The emission of smoke and fumes at surface fractures and vents is the usual indicator of an abandoned mine fire. These indications, however, are not necessarily located above the subsurface combustion zones. Aerial infrared photography can be used to determine temperature variations within a few inches of the surface, but is inappropriate when heated areas lie several hundred feet below the surface. Temperatures and gas samples taken at the base of boreholes are point source measurements. Their accuracy is limited to a very small volume near the sample point, particularly when the volume lies outside an area affected by natural underground ventilation.

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In order to locate a fire, it is necessary (1) to identify a parameter characteristic of the fire, (2) to measure the parameter through appropriate sampling methods, and (3) to interpret the sampling data correctly. The mine fire diagnostic method being developed by the Bureau of Mines satisfies these criteria; it is based on hydrocarbon desorption and controlled subsurface sampling. In this method, borehole temperature and pressure, and the concentration of low-molecular-weight hydrocarbons in the mine atmosphere are measured under natural or baseline conditions. These values are compared to those obtained when a suction fan is used to cause mine gases to flow from the surrounding underground areas toward the point at which the suction is applied (fig. 1). Differences in the concentration of hydrocarbon gases at various points underground can be related to the movement of combustion products in assumed directions from the source toward the suction point. The presence of hydrocarbon gases does not necessarily indicate active combustion throughout an area, but does indicate the presence of coal that is heated above normal subsurface temperature.

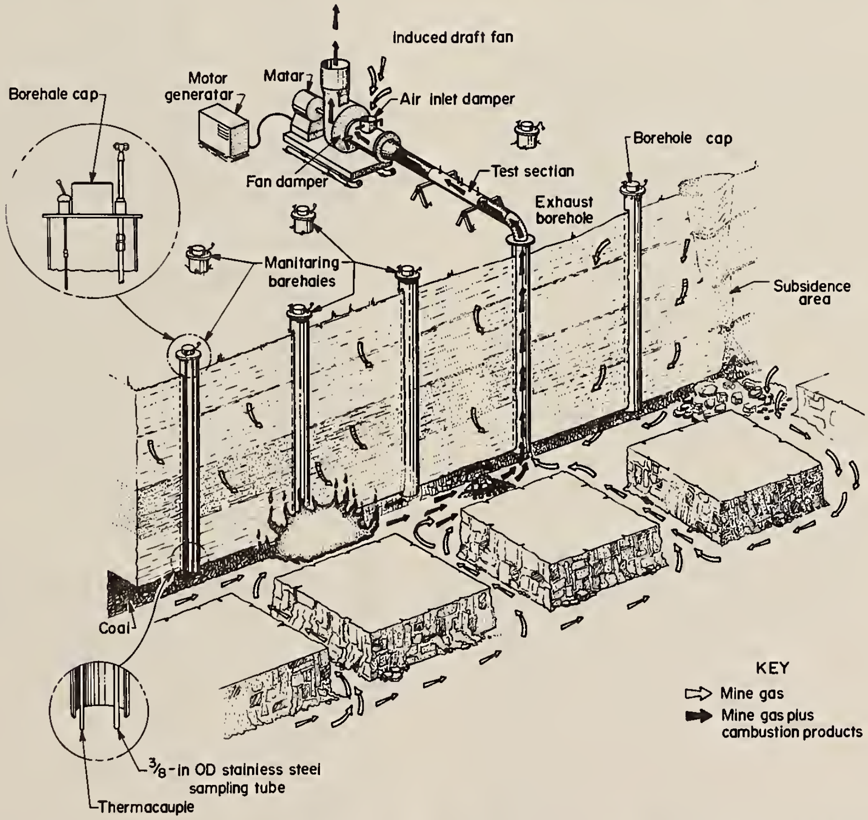

Figure 1.--Mine fire diagnostic technique. (Artist's version of an abandoned mine site application.)

The Bureau's mine fire diagnostic method has several advantages: (1) Changes in hydrocarbon emission are caused only by changes in temperature; (2) changes in hydrocarbon emission can be detected for temperatures below the ignition point of coal, thereby increasing the sensitivity of the method; (3) hydrocarbons can be detected at concentrations as low as 1 ppm; (4) the use of an appropriate ratio can eliminate the effects of sample dilution; (5) induced pressure effects - and therefore, fires - can usually be detected several hundred feet from the suction point; (6) operation of the system is fairly simple, requiring only readily available equipment and normal technical skills; and (7) it differentiates heated and cold areas.

COAL FIRE CHARACTERIZATION

Previous work (Kim 1974, Kim 1978) by the Bureau has shown that the desorption of low-molecular-weight hydrocarbon gases from coal is strongly temperature dependent. At ambient temperatures, gas desorbed from coal is primarily methane. When coal is heated, the rate at which gas is emitted increases, and hydrocarbons other than methane are also desorbed. Changes in the concentration of desorbed methane and the C_2 to C_5 alkanes can be detected at temperatures lower than 100° C.

In order to relate the concept of hydrocarbon desorption to changes in temperature, the Bureau conducted a laboratory study (Kim 1986) in which samples of coal and coal waste (table 1) were heated in a tubular combustion furnace. Gas samples were taken during heating and cooling phases of the experiment, and analyzed for oxygen, nitrogen, carbon dioxide, carbon monoxide, hydrogen, and the hydrocarbons, methane, ethane, ethylene, acetylene, propane, propylene, iso- and normal butane and pentanes.

Table 1.--Sample identification and analysis.

Sample	Source	Moisture pct	Ash pct	VM[1] pct	FC[2] pct	Btu
Albright waste	WV	9.1	42.3	17.5	31.2	6719
Anthracite #1	PA	2.3	8.2	7.0	82.6	13536
Anthracite #2	PA	5.0	12.0	4.8	78.1	12184
An[3] waste #1	PA	1.5	69.6	7.1	21.7	3492
An waste #2	PA	2.0	60.3	7.0	30.8	4940
Black Creek	AL	2.2	2.0	37.2	58.6	14655
O seam	CO	7.9	5.6	36.2	50.3	12368
Freeport	PA	1.6	6.1	37.8	54.5	14196
Illinois #6	IL	12.0	27.8	29.4	30.7	8417
Pittsburgh	PA	1.4	4.8	37.3	56.4	14205
Pocahontas #4	VA	1.0	10.5	16.6	71.9	13934

[1] VM: volatile matter.
[2] FC: fixed carbon.
[3] An: anthracite.

Since the concentration of methane and the concentration of higher molecular-weight hydrocarbons both increase with temperature, a concentration ratio was defined which relates both factors in a single parameter suitable for graphical presentation. This ratio, R1, is defined as:

$$R1 = \frac{(1.01\,[THC] - [CH_4])}{([THC] + c)} \times 1000$$

where: $[THC]$ = concentration of total hydrocarbons, ppm
$[CH_4]$ = concentration of methane, ppm
c = constant, 0.01 ppm.

The ratio R1 was defined to: (1) equal zero when and only when the concentration of total hydrocarbons was zero; (2) have a unique value when methane was the only hydrocarbon; (3) eliminate the possibility of division by zero, a constraint necessary for computer processing of data; and (4) increase as temperature increased. As defined, the ratio R1 is an increasing function of the percentage of higher hydrocarbons, has a value of zero when no hydrocarbons are detected, a value of 10 when methane is the only hydrocarbon, and a limiting value of about 1000. The only constraint on the use of R1 as an indicator of heated coal is that the concentration of methane in the gas samples be greater than 20 ppm. Below this level, the concentration of hydrocarbons in the sample could be below the current 1 ppm detection limit of standard gas chromatographic (GC) techniques; thus, changes in the hydrocarbon concentration might not be detected.

The results of the laboratory heating tests varied with the rank of coal. For bituminous samples, the concentration of hydrocarbons and the value of R1 generally increased during heating and decreased during cooling (table 2). The emission of hydrocarbons from the anthracite samples was very low, usually less than 20 ppm, and the higher hydrocarbons were not generally detected.

Table 2.--Variation in R1 with temperature.

	Temperature, °C								
	Heating					Cooling			
Sample	100	150	200	225	250	225	200	150	100
Albright Waste	30	40	50	75	400	125	60	30	10
Anthracite #1	130	10	80	10	10	10	10	10	10
Anthracite #2	10	10	10	10	10	10	10	10	10
An Waste #1	145	140	125	115	115	10	10	10	10
An Waste #2	10	10	10	10	10	10	10	10	10
Black Creek	150	200	350	440	540	400	250	125	10
D Seam	710	880	890	910	825	700	625	690	675
Freeport	50	70	80	150	325	275	225	10	10
Illinois #6	675	660	625	625	625	410	375	375	10
Pittsburgh	520	540	590	550	550	200	180	150	
Pocahontas #4	100	110	125	150	300	190	160	85	10

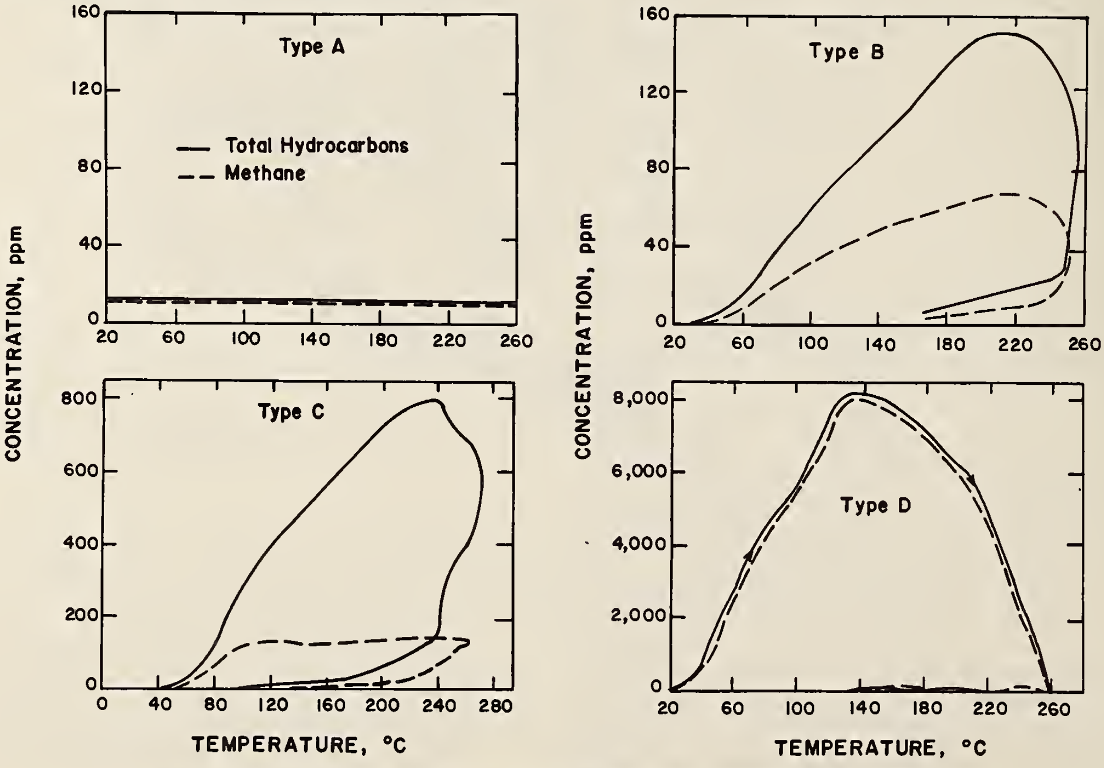

Figure 2.--Hydrocarbon emission from heated coal - types A through D.

The relative emission of total hydrocarbons and methane from the 11 samples could be described by 4 emission curve types (table 3). Type A emission, which was characterized by low hydrocarbon emission and no difference between methane and total hydrocarbons, was characteristic of all anthracite samples (fig. 2). In types B and C, the total hydrocarbon emission rate was greater than that of methane. In type D emission, the concentrations of total hydrocarbons and of methane increased rapidly and at similar rates. Hydrocarbon emission decreased rapidly during cooling.

Table 3.--Summary of hydrocarbon emission characteristics.

	[THC]max ppm	R1max	Emission type	Ratio type
Albright Waste	385	425	D	II
An Waste #1	85	150	A	III
An Waste #2	20	10	A	III
Anthracite #1	10	10	A	III
Anthracite #2	10	10	A	III
Black Creek	95	526	B	I
D Seam	615	885	C	I
Freeport	8550	450	D	II
Illinois #6	250	650	C	I
Pittsburgh	400	560	B	I
Pocahontas #4	400	370	D	II

Plots of the hydrocarbon ratios versus temperature were classified in three categories. For type I ratios (fig. 3), the R1 values during heating were higher than during cooling. Maximum values occurred around 250° C and were in the 600 to 700 ratio range. Those coals with types B and C hydrocarbon emission had type I ratios (table 3). Type II ratios initially increased at a lower rate than type I ratios. They increased rapidly above 200° C, and decreased at approximately the same rate during cooling, although the values during cooling could be higher than during heating. Maximum values of R1 were in the 400 to 600 ratio range. Coals which exhibited type D emission had type II ratios. Type III ratios exhibited little variation with temperature; these were from anthracite samples which had type A emission.

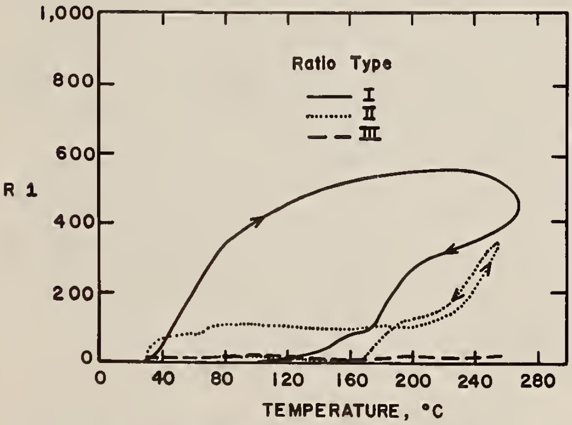

Figure 3.--Hydrocarbon ratios - types I, II, and III.

The laboratory determination of hydrocarbon emission ratios demonstrated that such ratios are strongly temperature dependent for bituminous samples. Generally, the values of the ratio R1 for bituminous coals can be interpreted on an empirical scale as:

R1	Relative Coal Temperature
0 to 50	Normal
50 to 100	Possible Heated Coal
> 100	Heated Coal

The ratio R1 was not as applicable to anthracite samples because of the lower rate of total hydrocarbon emission and the very low concentration of higher hydrocarbons.

The R1 ratio is not uniquely related to a particular coal temperature. It is, however, indicative of an average temperature condition, and over a period of time will increase with increasing temperature and decrease with decreasing temperature.

COAL FIRE DETECTION

The mine fire diagnostic method is based on the assumption that a sufficiently large negative pressure (vacuum) applied to underground regions will cause gases to flow from some distance towards the point of suction. Controlling the movement of underground gases overcomes the limitations of a point source measurement by allowing gases from a large region to be sampled at a single point; and by sampling at multiple points, it provides data for determining the presence or absence of fire along pathways between the sampling points.

The method is illustrated in figure 4. If a fire exists throughout a region (Case A), the flow of gases from right to left will cause combustion products to appear at each borehole. If a borehole lies outside the fire zone, combustion products will not appear at that hole (Cases B and C). To verify the location of heating, the applied suction is moved to other boreholes and the tests are repeated. The successful determination of combustion zones depends upon the ability to force and detect the movement of gases from these zones. Radially induced pressure effects are detectable as far as several hundred feet from a point of suction. The surrounding boreholes are capped during suction to control dilution by air. If the region is highly fractured or faulted, air will be drawn in from the surface. In most cases, however, the use of concentration ratios, which are independent of dilution, will still be reliable indicators of the presence or absence of fire, except when the incoming air reduces the hydrocarbon concentration below the detection limit.

To locate underground heated zones, a series of boreholes are drilled and cased to depths consistent with coal-bearing strata. The first series of holes is used to define general heated zones. The results from the first round of testing is then used to determine the placement of additional boreholes. A second round of tests is performed to verify the location of heated zones

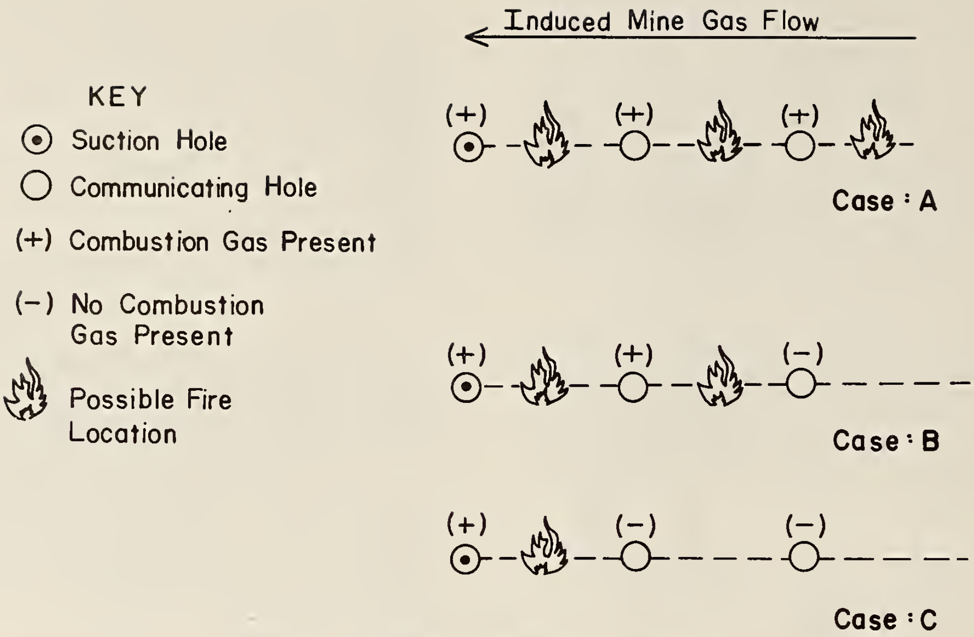

Figure 4.--Mine fire diagnostic technique .

and to establish the presence of a cold boundary. Although a variety of borehole casing dimensions have been used, it was found that an 8-in I.D. casing is preferred. With smaller diameter casing, most of the suction fan's output capacity is used to move the mine air from the bottom to the top of the borehole.

A set of communication studies is used to produce baseline data and communication data; both data subsets include static pressure, temperature, and gas concentrations at each borehole. Static pressure readings at surrounding boreholes are used to determine the pressure effect caused by suction. These data are used to draw a pressure contour which defines the area of good communication, that is, the area for which the data are considered valid. A flow probe in the intake piping of the fan is used to calculate the total flow through the fan.

Differences between baseline and communication measurements are calculated for the area for which the data is considered valid. The changes at each borehole can be classified as: (1) an increase in R1 (heating), (2) a decrease in R1 (cooling), or (3) no change during suction tests. To delineate the heated and cold zones it is assumed that increased hydrocarbons originated in a heated area beyond the borehole which lies on a straight line between the borehole and the suction point. Similarly, a decrease in hydrocarbons indicates a non-combustion or cold zone. Both heated and cold quadrant zones are drawn on a site map, within the pressure contour (fig. 5). By overlaying the possible combustion and non-combustion regions for each test, a composite map is drawn.
Liberal estimates of possible fire zones are mapped for each test; overlapping the results of all tests effectively bounds the possible fire zones through successive approximation. This technique defines probable combustion zones and also defines zones that show no signs of combustion, an important point in defining a fire area.

CASE STUDIES

The mine fire diagnostic method has been applied at three mine sites. It was used to define combustion zones and follow the progress of extinguishment efforts at an abandoned underground bituminous mine at Renton, PA. It was used to locate both heated and cold areas in an abandoned anthracite mine in Carbondale, PA. Currently, it is being used to define the combustion area at an abandoned bituminous mine in Large, PA.

Renton Mine Fire Project

The Renton Mine Fire project was the initial phase in the development of the Bureau's Mine Fire Diagnostic Methodology. This abandoned mine fire site encompasses an approximately 60-acre region near Renton, which is characterized by several large subsidence holes and venting areas. One hundred nineteen boreholes were installed at the site. They were primarily for monitoring purposes, but some were later used as water injection or grout injection points. The mine fire diagnostic technique was used at the Renton site to delineate three separate combustion regions. Figure 6 shows the variation of R1 with time at 3 randomly selected boreholes. Boreholes 33 and 57 are heating with time, while borehole 14 is cooling with time. The ratio R1 was used to monitor a fire extinguishment technique in which water was injected into the heated areas while a suction fan was used to draw heated air from the mine (Chaiken et al. 1984). Through the applied diagnostics it was possible to determine which areas were quenched, and which heated regions were not quenched and/or were spreading.

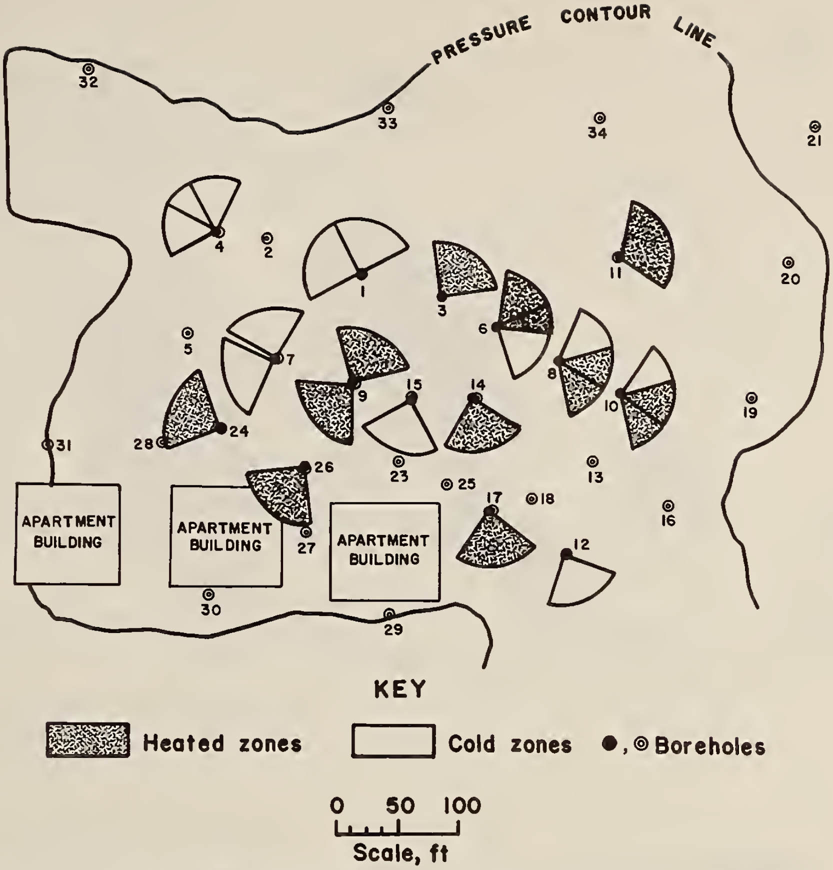

Figure 5.--Quadrant mapping of heated and cold zones after two communication tests. (Boreholes 3 and 26 are the suction points.)

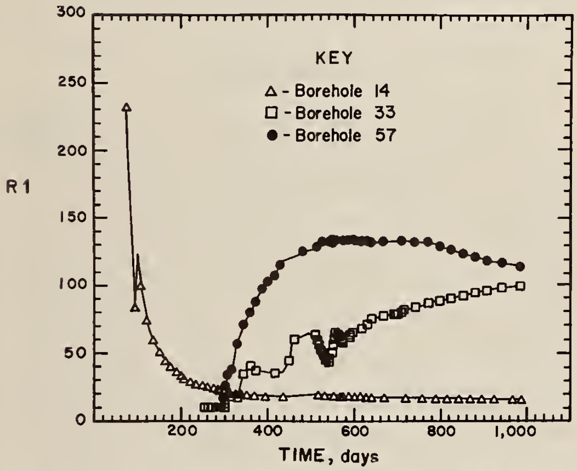

Figure 6.--R1 versus time curves for three randomly selected boreholes. (Baseline measurements taken at Renton, PA).

Carbondale Mine Fire Project

The Carbondale fire site lies within the anthracite coalfields of north-eastern Pennsylvania. It is thought that the heated zones are remnants of a 1946 city dump fire that had spread to abandoned underground coal mine workings (Chaiken et al. 1983). Attempts were made to extinguish the fire in 1950 by flushing and in 1974 by excavation. The extinguishment efforts were assumed successful until recent abnormal snow melt was observed. The Office of Surface Mining Reclamation and Enforcement (OSMRE) installed a series of 34 boreholes to monitor temperatures and CO concentrations throughout the 8-1/2-acre site. The Bureau of Mines was asked to assist in locating the heated zones.

The use of the mine fire diagnostic method at Carbondale is considered a test under nonideal conditions for the following reasons: (1) The emission rate for methane and low-molecular-weight hydrocarbons from anthracite is very low, and does not exhibit strong temperature dependence; (2) many of the boreholes were cased through the underlying coal seams; (3) the borehole diameters and depths were such that half of the suction fan's rated pressure drop would be used to overcome resistance to airflow in the pipe; and (4) a large rock fracture line crossed the region, possibly limiting the effectiveness of the communication tests. To overcome these conditions, several adaptations were made to the mine fire diagnostic method. Since the ratio R1 from laboratory tests was not expected to be a good indicator of heated coal, the change in the absolute concentration of methane was used for the index of combustion activity. Two suction fans rated at 40-in vacuum

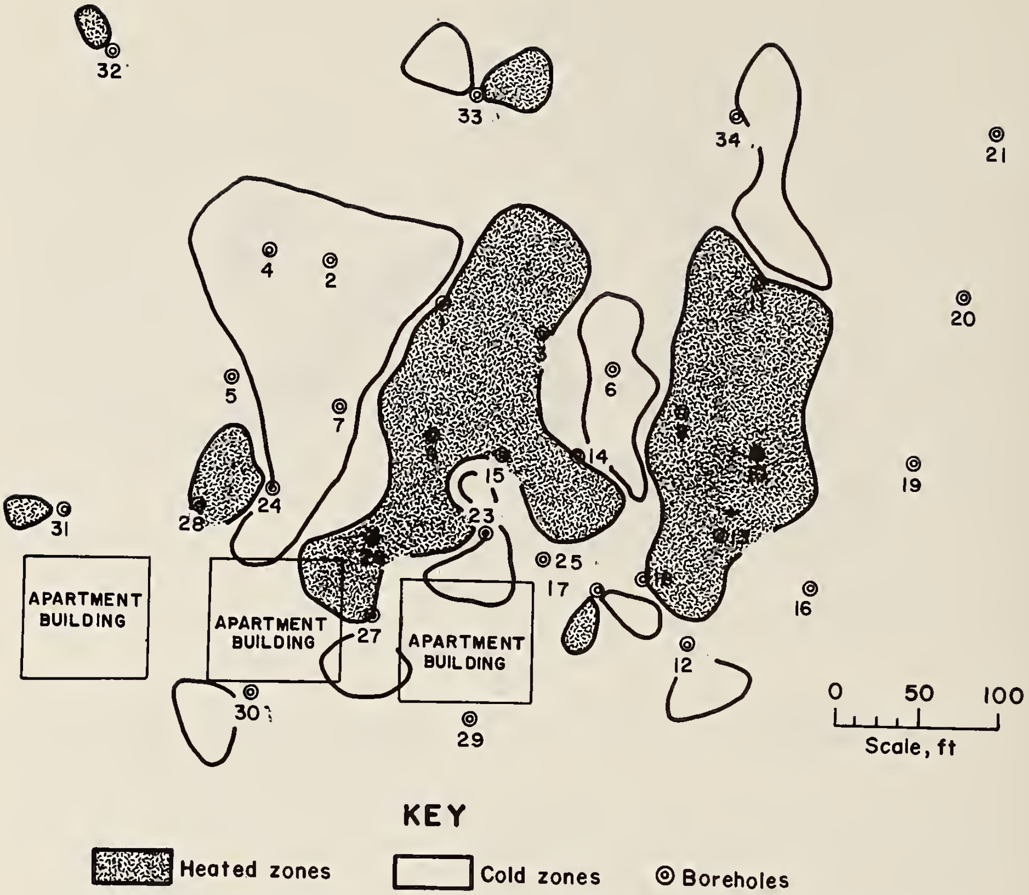

Figure 7.--Delineated heated and cold zones using the mine fire diagnostic technique. (Results of 25 communication tests at Carbondale, PA).

w.c. were connected in series in order to provide sufficient power to influence the movement of air in the mine.

The tests conducted at Carbondale located both heated and cold areas despite the nonideal conditions. The areas that show either evidence of combustion or no evidence of combustion activity, respectively, are delineated on the map of the Carbondale site (fig. 7). The seven noncontiguous heated zones that were identified included one region which had not been detected using temperature and CO concentration measurements alone.

Large Mine Fire Project

This fire is at an abandoned mine site in Large, PA. Although the project is in its early stages of development, a total of 8 mine fire diagnostic tests have been conducted at the 15-acre site. The diagnostic technique has been used to confirm the existence of fire and to obtain a preliminary estimate of the location of heated areas. These results have been used to place 25 more boreholes for additional testing to determine the location of the fire and to establish the location of a cold boundary. At Large, variations in R1 have indicated changes in subsurface conditions during long-term baseline (without suction) monitoring.

CONCLUSIONS

Laboratory results and field studies support the effectiveness and applicability of the Bureau's mine fire diagnostic technique in locating and monitoring abandoned mine fires. For the bituminous samples studied, values of the concentration ratio R1 increased with increasing temperature and decreased during cooling. Although values of R1 do not correspond to a particular temperature, elevated values of R1 are due only to the presence of heated coal. Time-dependent monitoring of changes in R1 reflect changes in the average temperature of the coal. The ratio R1 was not applicable to anthracite samples because of the lower rate of hydrocarbon emission and the very low concentration of higher hydrocarbons. However, borehole measurements of the variations in the absolute concentration of methane (often several hundred ppm in the case at Carabondale) strongly suggests that it is indicative of changes in coal temperature and therefore can be used when R1 is not appropriate.

The mine fire diagnostic method incorporates a sampling method that increases the detection zone of normal point source measurements by inducing gas movement. Measuring changes in a characteristic of the moving gas, i.e., hydrocarbon concentration, and plotting the results as vectors (magnitude and direction) rather than as points (magnitude), provides interpretive insight and bounds the area affected by combustion.

The Bureau's mine fire diagnostic methodology includes (1) a single parameter, characteristic of heated coal, (2) a sampling method which effectively expands the sampling volume, and (3) an interpretive method which defines heated and cold areas. These factors make the Bureau's methodology a significant improvement in locating and monitoring abandoned mine fires.

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PROBLEMS OF RECLAIMING AREAS AFFECTED BY MINE FIRES - A CASE STUDY[1]

K. K. Malhotra and P. R. Sinha[2]

Abstract.--Fires in underground coal seams in the Jharia Coalfield of India often break through to the surface, causing severe problems of subsidence, air pollution, and destruction of surface vegetation. The Indian Government has begun a program to extinguish these fires and reclaim the damaged areas. One of these efforts, the Jogta fire project, is described in this paper. The reclamation effort at Jogta consisted of: (1) excavating the subsidence cracks and filling them with impermeable material; (2) leveling, compacting, and sealing the entire surface to prepare it for the use of heavy, rubber-tired equipment; (3) hauling in quarry refuse to establish a subsoil base with a slope of 5 to 10 pct to minimize erosion by rainfall; (4) hauling in topsoil to further seal the surface and provide a medium for plant growth; (5) irrigating the area and planting with over 30 hardy species of vegetation; and (6) creating ponds to take advantage of the surface profile resulting from backfilling operations. These efforts have resulted in the reestablishment of pre-mining ecological conditions. The procedures, problems, and results of various aspects of the reclamation effort are described.

INTRODUCTION

The coal industry of India is about 200 years old; the major coalfields, shown in figure 1, occur in sedimentary formations in the eastern half of the country. Most of the coal is bituminous, with some lignite, and is classified as coking or non-coking for reserve estimation. Table 1 summarizes the estimated reserves of each coal type and shows that the supplies are expected to last only about 100 years at present rates of depletion (Tandom, 1987). Only the Northeastern and Jharia Coalfields contain coals with acceptable coking characteristics. Although the Northeastern coals have the best coking properties, they have a high organic sulfur content that cannot be reduced through standard washing techniques; this makes them unsuitable for use by the steel industry. Jharia coals are lower in sulfur (albeit higher in ash) than Northeastern coals, making them the most desirable coking coals in the country.

The Jharia Coalfield has about 19 mineable seams, labeled 0 through 19 from the bottom to the top of the stratigraphic sequence. Figure 2 shows the vertical locations, thicknesses, and spacing of the seams at the Angarpathra and Gaslitan collieries, which are typical of the mines operating in the area. The upper 11 seams (9 to 19) have less ash than the lower seams and therefore have better coking characteristics; these are the seams that have been mined most extensively to date.

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[1] Paper presented at the 1988 Mine Drainage and Surface Mine Reclamation Conference sponsored by the American Society for Surface Mining and Reclamation and the U.S. Department of the Interior (Bureau of Mines and Office of Surface Mining Reclamation and Enforcement), April 17-22, 1988, Pittsburgh, PA.

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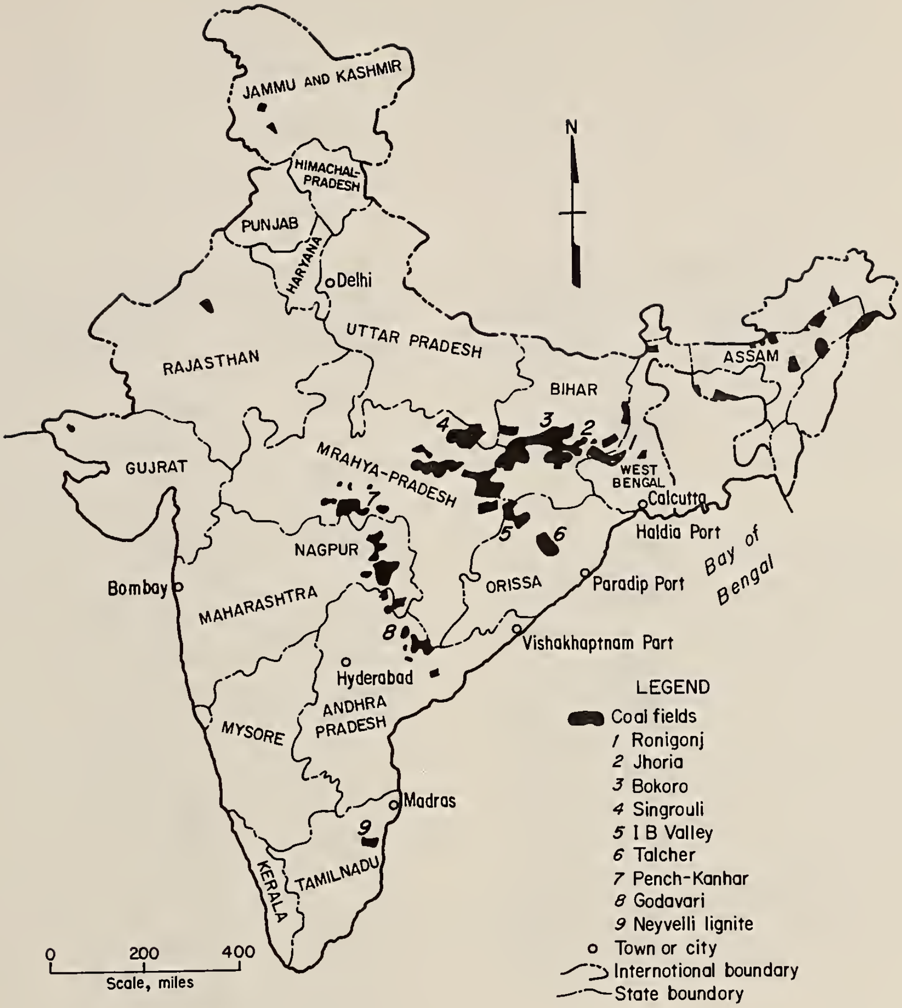
JAMMU AND KASHMIR
HIMACHAL-PRADESH
PUNJAB
HARYANA
Delhi
RAJASTHAN
UTTAR PRADESH
BIHAR
ASSAM
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MRAHYA-PRADESH
WEST BENGAL
Calcutta
Haldia Port
Bay of Bengal
NAGPUR
ORISSA
Paradip Port
Bombay
MAHARASHTRA
Vishakhaptnam Part
Hyderabad
ANDHRA PRADESH
MYSORE
Madras
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LEGEND
Coal fields
1 Ronigonj
2 Jhoria
3 Bokoro
4 Singrouli
5 I B Valley
6 Talcher
7 Pench-Kanhar
8 Godavari
9 Neyvelli lignite
Town or city
Internotional boundary
State boundory

Figure 1.--Major coalfields of India.

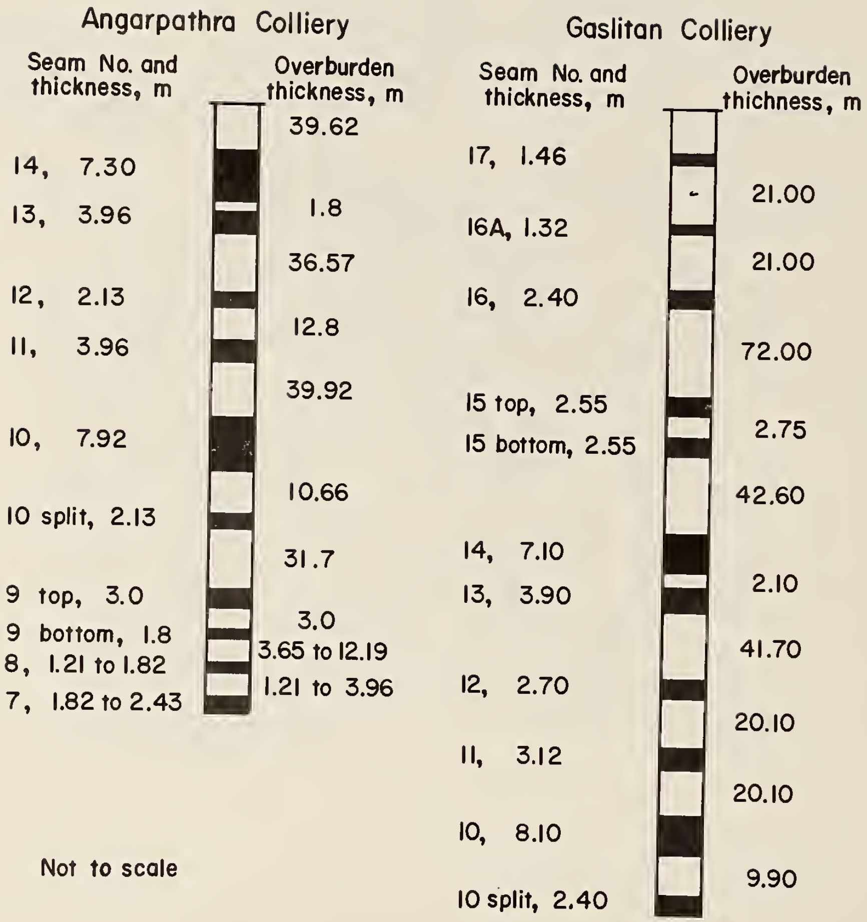
Angarpathra Colliery
Seam No. and thickness, m
Overburden thickness, m
39.62
14, 7.30
13, 3.96
1.8
36.57
12, 2.13
12.8
11, 3.96
39.92
10, 7.92
10.66
10 split, 2.13
31.7
9 top, 3.0
3.0
9 bottom, 1.8
3.65 to 12.19
8, 1.21 to 1.82
1.21 to 3.96
7, 1.82 to 2.43
Not to scale
Gaslitan Colliery
Seam No. and thickness, m
Overburden thichness, m
17, 1.46
21.00
16A, 1.32
21.00
16, 2.40
72.00
15 top, 2.55
2.75
15 bottom, 2.55
42.60
14, 7.10
2.10
13, 3.90
41.70
12, 2.70
20.10
11, 3.12
20.10
10, 8.10
9.90
10 split, 2.40

Figure 2.--Vertical location, thickness, and spacing of coal seams at the Angarpathra and Gaslitan Collieries in the Katras area.

Table 1.--Estimated reserves of coking and non-coking coal in India.[1]

Coal type	Recoverable reserves as of 1-1-80 (m.tonnes)	Depletion during 1980-94 (m. tonnes)	Life of reserves at 1994-95 level of production (years)
Coking	6,629	563	93
Non coking	32,357	2,168	116

[1] After Tandom 1987.

Unfortunately, the upper seams are very susceptible to spontaneous combustion, resulting in many mine fires during the process of extraction. It is estimated that over 60 pct of the mine fires in India have started in this manner. These fires often extend upward to the land surface because: (1) the seams are very thick with little overburden; (2) close vertical spacing between seams allows fires in lower seams to ignite higher ones; (3) old room-and-pillar workings provide a ready supply of oxygen; and (4) natural topsoil is thin and allows passage of air through subsidence cracks. Once a fire breaks through to the surface, it is very difficult to control due to the synergistic effects of underground coal combustion, strata fracture and subsidence, and passage of air from the surface through subsidence cracks.

Mine fires in the Jharia Coalfield are quite extensive and severe. The first was reported in 1916, and many have been burning for decades; a total land area of 17.3 km^2 has been damaged to date. Because the fire zones are in densely populated areas (venting has occurred within 15 m of residences), they must be controlled and the land must be reclaimed as soon as possible. In addition to heat and subsidence problems, the fires pose a significant human health hazard through the release of gaseous and particulate contaminants from surface vents. Loss of scarce and valuable coking coal reserves is another reason for immediate control of these fires. It has been estimated that 1.86 billion tonnes of coal are now inaccessible because of proximity to burning areas (Coal Lignite Working Group, 1985).

When the Indian Government took over the management of the nation's coal mines in 1971-73, it set a target date of 1995 for extinguishment of all 70 fires known to exist at that time (CMPDI, Ltd., 1986). Bharat Coking Coal Ltd., the public sector enterprise that now operates the mines of the Jharia Coalfield, is responsible for the extinguishment and land reclamation effort. This paper describes the methods, problems, and results of one of these efforts, the Jogta fire project.

JOGTA FIRE PROJECT

Fire Site

The Jogta fire started in 1941 due to spontaneous combustion of coal in a pillar extraction section of a mine operating in seams 13 and 14, about 20 to 50 m below the land surface. Attempts were made first to extinguish the fire using underground seals to cut off the air supply to the panel. These were ineffective, and by 1953 the fire had reached the surface. It spread to the north, east, and west and began to threaten neighboring mines, railways, roads, streams, and residences (Sinha and Malhotra, 1980). By the time control measures were begun in 1980, the fire had spread over an area of 18.72 ha, with an east-west strike length of about 1 km. The District Board road and some residences had subsided, and the fire was within 30 m of a stream and other residential areas.

The surface areas affected by the fire had some of the most hazardous environmental conditions imaginable, which greatly hindered the extinguishment and reclamation effort. Soil temperatures (when any soil was present) in areas where the fire had penetrated the surface were 250° to 650° C (Malhotra, 1986). Subsidence cracks as wide as 2 m occurred throughout the area, discharging steam, smoke, and flames which sometimes shot as high as 6 m above the surface. Subsidence was particularly common and unpredictable during the monsoon season when the water added weight and lubrication to the strata. Pollutants such as carbon monoxide and particulates were severe; vegetation was practically nonexistent. In areas away from the damaged surface, but above the underground fire zone, the temperature 1 m below the surface was 40° to 50° C. Vegetation occurred sporadically, and only during the monsoon season.

Extinguishment and Reclamation Plan

Given the extreme environmental conditions at the fire site, remedial measures had to be precise and thorough yet cautious and deliberate; the former was to ensure that the fire would be completely extinguished, and the latter to protect the workers' health and safety. The general approach toward reclamation consisted of (Malhotra and Banerjee):

1. Excavating the subsidence cracks and filling them with impermeable material to prevent oxygen from reaching the fire;

2. Leveling, compacting, and sealing the entire surface to prepare it for the use of heavy, rubber-tired equipment;

3. Hauling in quarry refuse to establish a subsoil base with a slope of 5 to 10 pct to minimize erosion by rainfall;

4. Hauling in topsoil to further seal the surface and provide a medium for plant growth;

5. Irrigating the area and planting with over 30 hardy species of vegetation;

6. Creating ponds to take advantage of the surface profile resulting from backfilling operations.

The procedures, problems, and results of various aspects of the reclamation effort are described below.

Equipment Selection and Site Preparation

The intense heat of the surface and the constant threat of subsidence were the two major constraints governing the selection and operation of equipment. For the initial phase of crack excavation and sealing, comparatively light (21-tonne), track-mounted bulldozers were chosen. The lighter weight and greater bearing area of these machines lessened the danger of equipment-induced subsidence. If this did occur, the bulldozers were better able to retrieve themselves from the sunken area than heavier, tire-mounted equipment. In addition, the engines and fuel tanks of the bulldozers were relatively high off the ground, making them less susceptible to damage from the hot soil surfaces. Even so, digging time was limited to 3 hours at a stretch to protect the lubrication of the bulldozer undercarriage. In areas of intense heat release, the excavated surface had to be covered with about 600 cm of topsoil before heavier, rubber-tired vehicles could be used.

After the bulldozers had stabilized and sealed the surface, quarry refuse for the subsoil base and topsoil for the final cover were hauled in by 35-tonne dump trucks. The fill material was compacted by the truck tires and special compacting equipment with an impact load of 20 tonnes. The quarry refuse initially was leveled to a maximum slope of 10 pct; however, in several areas this proved to be insufficient to prevent gully formation during the monsoon season. Maximum slopes were subsequently reduced to 5 pct before topsoil was emplaced. In areas where higher slopes had to be maintained, such as against a rail head where a 25 pct profile was required, biological soil binders were used to prevent erosion, and dense planting of Agave Sisalana and grass was employed to improve stability. In other areas, large sandstone pieces in the upper 2 m of subsoil fill material resulted in highly permeable zones that allowed venting to redevelop. These had to be reexcavated, refilled, and recompacted before further reclamation could take place.

Topsoil in the Jharia Coalfield area was very scarce, which greatly increased the time and cost associated with the reclamation effort. Topsoil thickness varied according to sealing and plant growth requirements; the initial topsoil thickness was limited to 15 cm wherever possible. Sealing was considered to be effective if the subsurface oxygen content was 3.5 pct or lower.

Worker Health and Safety Hazards

The initial excavation and sealing of the surface fire zones was an extremely hazardous task. For each bulldozer operator, at least three helpers were required to stand at a distance and warn him of impending subsidence. Poor visibility due to dust (dry season) and steam (wet season) made this process even more difficult. Operators and helpers were all endangered if a ground collapse did occur and the machine had to be retrieved from the hole.

Carbon monoxide poisoning was a constant threat; work was limited to 3 hours per day, 2 days per week for each crew to prevent excessive exposure. Even with these restricted hours, workers commonly developed headaches which remained for 3 days after each day of work (Malhotra, 1987).

Revegetation Efforts

The scant topsoil available for revegetation was usually of poor quality due to: (1) extreme heat and salt deposition by steam moving upward from burning underground areas; and (2) erosion and leaching by rainfall. Table 2 lists the soil nutrients typical of intensely vented areas (Malhotra, 1987). The high conductivity (salinity) of these soils inhibited the germination and growth potential of plants intended for revegetation. This problem was compounded by the high salinity of the subsoil layer of quarry refuse (conductivity of 4.5 to 29 mmhos/cm). The nutrient content of the topsoil was enhanced by the addition of chemical fertilizers at rates of 150 kg/ha during transplantation and 100 kg/ha per stage in three stages at 3- to 4-week intervals after planting.

Before planting began in 1981, the entire area to be reclaimed was irrigated for one year in order to allow topsoil to seal minute cracks and to delineate areas requiring further sealing. Irrigation water was pumped in from a neighboring mine and from a dammed intermittent stream on the east side of the fire zone. Depending on weather conditions, the area was irrigated at 1- to 3-week intervals.

The first few planting seasons were not very successful; for example, of the 2,500 saplings planted during 1981, only 52 plants of Gmelina Arborea survived. This suggested that heat and pollutants from the subterranean fire zone were still reaching the surface. In subsequent years, however, survival rates of other species increased considerably, up to 95 pct in some cases. Subsurface oxygen content in most of the revegetated areas was reduced to below 2 pct. Initial plant species included Eucalyptus, Pongammia, Jacaranda, and Peltophorum, with diversification carried out in later plantings. Over 30 plant species were introduced, with greater survival rates for species that were relatively insensitive to saline soils. As mentioned earlier, Agave Sisalina was successful in stabilizing areas with steep slopes.

Table 3.--Typical soil characteristics and nutrients in intensely vented areas.[1]

Sample	pH	Conductivity (mmhos/Cm)	Organic carbon (%)	P (kg/ha)	K (kg/ha)
1	5.1	0.10	0.29	5.1	907.2
2	5.5	0.08	0.50	3.8	201.6
3	6.4	0.30	1.44	3.2	179.2
4	4.7	4.50	1.31	3.8	358.4
5	5.3	1.50	0.87	3.2	156.8
6	7.6	29.0	0.54	10.3	168.0
7	7.5	25.0	0.78	6.6	1,120.0

[1] After Malhotra 1987.

Ecological Development

The reclaimed and revegetated fire areas are now green and capable of supporting ecological development, a welcome contrast to the scenes of devastation that existed in 1980. In two areas the original land profile was used in the reclamation process to create ponds capable of supporting aquatic life. The ponds were developed by creating two embankments with fill, repeatedly compacting the fill to decrease permeability, emplacing a thick layer of topsoil mixed with organic matter, and providing supplemental food for fish until natural aquatic biota were established. Microorganisms began to grow in the ponds within a year, and fish were added during the 1985 growing season. Although fish growth during the first year was lower than normal, the growth in subsequent years has been satisfactory. Carp stocked in 1985 have attained a weight of around 1 kg, about normal for this locality. Wildlife has also been introduced satisfactorily, even though the specie of deer (black buck) is known to be sensitive to conditions of captivity.

SUMMARY

The Jogta fire project has shown that it is possible to completely reclaim an area of the Jharia (India) Coalfield that had been devastated by underground and surface mine fires. The ecosystem of the locality has been returned to the premining state, and efforts are now underway to improve the situation by establishing green belts, zoological parks, and fisheries. In addition, the reclamation effort has completely eliminated a severe source of gaseous and particulate air pollution and alleviated the threat of subsidence damage to nearby residences.

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STRUCTURES AND GROUND DAMAGES OVER ABANDONED MINE LANDS[1]

S. M. Hsiung, P. M. Lin, and S. S. Peng2

Abstract.--Damages to surface structures and ground surface above abandoned mine lands have been found in many regions of Pennsylvania and West Virginia. Many cases of damage can be attributed to abandoned mine failures or some other known causes. However, in cases the causes cannot be easily identified. Twenty cases of subsidence damage to dwellings have been investigated. Among them fourteen cases were determined to be abandoned mine failures based on the identification criterion developed in this research; three cases were due to differential settlement; two cases were due to soil piping or drainage problems; and one case was due to active mine subsidence.

In this paper, the procedures of investigation and instrumentation applied to the case studies are described. The damage patterns, the location of subsidence epicenter and the severity of damage derived from the information collected are illustrated. The results obtained from the instrumentation such as the inclinometer and Sondex measurements are discussed. Based on those intensive case studies some general findings and trends are obtained. For instance, the basements of the dwellings likely are subject to more severe damage than the upper structures. These features are also discussed in detail in this paper.

INTRODUCTION

Damages to the ground surface and surface structures above abandoned coal mine lands have affected about 2 million acres in 30 states (Johnston and Miller, 1979). This problem appears to be the most severe in Pennsylvania, Illinois, and West Virginia (HRB - Singer, Inc. 1977). Approximately 57% of the total subsidence prone areas in the U.S. are located in Pennsylvania and West Virginia (Johnston and Miller, 1979). These damages can be attributed to mining-related or nonmining-related causes. Federal abandoned mine subsidence remedial program and private insurance companies subsidence insurance policies only take care of mining-related subsidence. For purposes of damage compensation and underground stabilization, it is essential to identify the real causes of the damages. In order to identify the real causes of the damages, the damaged features associated with each possible cause and the mechanism of each damage feature should be well understood.

Twenty cases of subsidence damage to dwellings were investigated. Among them fourteen cases were due to abandoned mine failures; three cases were due to differential settlement of backfilled materials; two cases were due to soil piping or drainage problems and one case was due to active mine subsidence (Peng and Hsiung, 1986 and 1987). Based on the subsidence features five of

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[1] Paper presented at the 1988 Mine Drainage and Surface Mine Reclamation Conference sponsored by the American Society for Surface Mining and Reclamation and the U.S. Department of the Interior (Bureau of Mines and Office of Surface Mining Reclamation and Enforcement), April 17-22, 1988, Pittsburgh, PA.

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the twenty cases were pothole subsidence and the remainder were sag or trough subsidence.

In this paper the approach and procedures of the investigation will be briefly discussed. The instrumentation will be reviewed. The data from some of the cases will be briefly discussed. The damage to the ground surface and structure, the links between the ground movement, ground damage and structure damage will be discussed and analyzed.

APPROACH AND PROCEDURES

The approach and procedures for the study of subsidence over abandoned mine lands have been established by the AML subsidence research group in WVU, Mining Engineering Department. Time is essential because the damaged conditions may be disturbed and the exposed features may disappear. Therefore, a site investigation is always the first step for AML subsidence research because most of the information must be collected from the subsidence site, especially during the first time reconnaissance. For most cases the causes, damage pattern, and the status of ground movement can be determined by the obtained information. The information mainly consist of six categories such as: (1) general information, (2) structure information, (3) surface condition, (4) geological information, (5) geometry and characteristics of the subsidence, and (6) mining activity. Each category will consist of several sub-categories. In order to make sure that a complete set of information can be collected a site investigation checklist has been developed by this research group. Table 1 is a site investigation checklist (Peng and Hsiung, 1987) which provides a guideline for inspectors to collect a complete set of information during the site reconnaissance.

With the data collected from a site investigation, a hypothesis should be established to clear up the logic and narrow down the number of possible causes. In order to determine the cause of the damage, the cause identification system with an identification list (Table 2) (Lin et al., 1987; Peng and Hsiung, 1987) have also been developed by this group to evaluate the most possible cause. If the cause cannot be determined due to insufficient data, an in-depth exploration should be adopted.

An in-depth exploration mainly consists of surface and subsurface measurements and instrumentations including surface survey, borehole TV camera examination, crackmeter, inclinometer and Sondex settlement measurements. The results can be used to determine the cause(s) of the damage, the direction and magnitude of movements, and help to design a better remedial program.

GROUND SURFACE DAMAGES DUE TO SUBSIDENCE

When subsidence occurs several types of ground damages will be induced. The most common damages are depressions, cave-in pits, ground cracks, and compression ridges. The ground depression is associated with trough or sag subsidence. Its mining-related causes are pillar and floor failures; non-mining-related causes are differential settlement on the backfilled area, fluid withdrawal and organic soil drainage. A ground depression is a gentle settlement over a broad area which may range from a few tens of feet to hundreds of feet in diameter while the depth of depression ranges from 2 to 4 feet for mine subsidence. The depth of the depressions due to non-mining-related causes is relatively unknown but a 30-feet depression has been reported due to fluid withdrawal (Christian and Hirschfeld, 1974).

The cave-in pits are most likely associated with potholes, sinkholes or chimney subsidences. Their mining-related cause is roof failure while the non-mining-related causes are limestone solution and soil piping. The newly developed cave-in pits are likely to be steep-sided with straight or bell-shaped walls depending on soil type. The diameter of cave-in pits ranges from 2 to 40 feet but most of them are less than 16 feet in mine subsidence (DuMontelle and Bauer, 1983). The depth of cave-in pits is about 6 to 8 feet for mining-related cases and the coal seams are less than 165 feet deep (Bauer and Hunt, 1981). For the non-mining-related cave-in pits, the diameter ranges from a few feet to 10 thousand feet and the depth ranges from a few feet to 90 feet (Newton, 1984). All the pothole subsidence cases investigated in this research showed that the diameter of the holes ranged from 2 to 19 feet; the depth was about 2 to 17 feet; and the coal seam was about 20 to 60 feet deep (Peng and Hsiung, 1986).

The ground cracks which occur at the margin of the depression and cave-in pits are the result of convex bending and are associated with the stretching of the ground surface. Generally, the ground cracks at the margin of the depression and cave-in pits indicate the location of the maximum tensile strain (peng, 1987). Beyond this maximum tensile strain zone, structures and ground damages are usually minor or nonexistent. Therefore, a subsidence damaged area can be determined by locating the ground cracks. In general, ground cracks are wider, more abundant and extensive near cliffs and steep terrain than they are in flat or gently rolling topography. Moreover, ground cracks are more often located at the asphaltic pavement than that at soil zone since asphat is more brittle than soil and can take less stress. Figure 1 shows that a ground crack was about 2 inches wide across through the width of the asphaltic road but the crack did not develop at the soil.

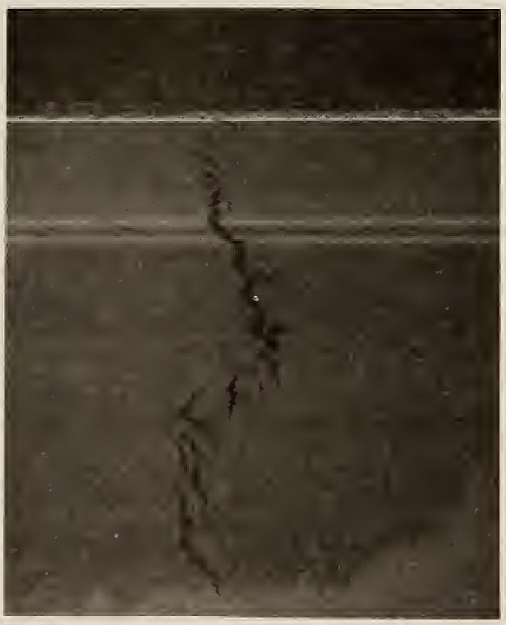


Fig. 1 Crack developed on the asphaltic road but did not develop on the shoulder (soil zone)

Table 1.--Subsidence Investigation Checklist.

1. General Information
   - A. Name(s):________________
   - B. Address(es):________________
   - C. Location: (See Fig.)________________
     ____
   - D. Date of initial occurrence________________
   - E. Date of investigation________________

2. Structure Information
   - A. Background and history of the problems
     - (a) History of damage________________
     - (b) History of similar events in the vicinity________
       ____
     - (c) Age of structure________________
   - B. Type of construction and material
     - (a) Type of house: with slab____ with crawl space____
       with full basement_____or partial basement______
     - (b) Type of construction and material: frame________
       brick__________ brick veneer__________
       concrete block________ stone veneer_______
   - C. Damage description (with drawings or photographs)
     - (a) 1st Floor: ceiling_________floor_________
       utility_________internal wall__________
       external wall____________
     - (b) 2nd Floor: ceiling_________floor_________
       utility_________internal wall__________
       external wall____________
     - (c) Basement: ceiling_________ floor_________
       utility_________internal wall__________
       external wall____________
   - D. Drainage system (with drawing)
     - (a) Downspout discharging points and conditions
     - (b) Location and condition of sewage/water lines

3. Surface Conditions
   - A. Topographic features (with tophographic map)
     - (a) Landform: flat_____ slope______ dip______%
       direction_____ natural ground_______backfill___
     - (b) Special features (e.g. highwall, road cut, creek,
       pond, etc.)________________
   - B. Soil
     - (a) Type of soil________________
     - (b) Conditions of top soil: dry______damp______
       saturated______coarse-grained______
       medium-grained________fine-grained_________
     - (c) Specific characteristics________________
   - C. Local drainage, springs, and any water problems_____
     ____

4. Geological Information
   - A. Surfacail geology
     - (a) Geological map: yes(included)_____no_____source_____
     - (b) Major rock type________________
     - (c) Structure patterns: faults______strike_____dip____
       joints_______strike____dip____steps_________
     - (d) Hydrological information: elevation of watertable
       ___________status of aquifer___________
   - B. Borehole information
     - (a) Borehole(s): yes_____no______source____________
     - (b). Core logging: yes______no_______source__________

5. Geometry and Characteristics of the Subsidence
   - A. Geometry of the subsidence
     - (a). Type: sinkhole_______trough______heave_______
       step_________crack_______
     - (b). Size: diameter (or width)_______length________
       depth_________inclination___________
   - B. Location of the ground damage and the damaged Structure
     (with description, drawings and photographs____________
     ____
   - C. Date of occurrence and its current status
     - (a). Date of occurrence:________________
     - (b). Status: stable________unstable_______unknown_______

6. Mining Activity
   - A. Mining status and mining method
     - (a). Status: active______abandoned______unknown________
       date of mining ceased______________
     - (b). Method: room and pillar_______ Longwall__________

Table 1 Subsidence Investigation Checklist (Cont'd)

Strip______________
     - (c). Company name:________________
   - B. Mine map and layout
     - (a). Map: available (attachedd)______not available_____
       Unknown___________
     - (b). Mine layout: length____________width______________
     - (c). Seam: name________________thickness_________
       depth___________
   - C. Location of mine workings vs surface subsidence and damaged structures (with drawing)

Recorded by________________

Date________________

Table 2 Subsidence Identification List

Specific Characteristics & Features	C	L	LS	FA	ES	OS	SP	FW	DS
Mined out coal seam	C								
Pothole on the surface (coal seam < 165 ft. deep)	C								
Depression on the surface (small to medium area)	C								
Fluid withdrawal in the area								FW	
Polygonal crack pattern								FW	
Large scale of depression, earth fissure or fault								FW	
Active ground movement all the time						OS		FW	DS
Hill or slope area		L							
Newly formed hummocky, scarp, steplike ground		L							
Moved blocks of rock, or displaced posts or poles		L							
Tilted trees and utility poles		L							
Transverse and radial cracks on the hill		L							
Wavy appearance in the driveways or sidewalks					ES				
Puffy or "popcorn" texture					ES				
Soil is sticky when wet but is hard when dry					ES				
Floor heaves when soil is wet, but settles when dry					ES				
Ground moves seasonally or periodically				FA	ES				
Floor heaves in cold weather and settles in warm weather				FA					
Stone nets, garlands and stripes on surface				FA					
Sheets- and lobes-shaped unconsolidated sediments				FA					
Thick frozen ground				FA					
Carbonate rock formations located near ground surface			LS						
Karst topography			LS						
Circular cracks on the surface	C		LS				SP		
Areas of vegetable stress caused by lowering of water table			LS						
Backfilled area									DS
Settlement starts right after structure is built									DS
Settlement rate is the highest in the beginning and is time dependent									DS
Outlets available							SP		
Potholes on the surface			LS				SP		
Loess, silt, uncemented sandstone and sand bed area							SP		
Damages develop quickly	C		LS				SP		
Organic soil exists						OS			
Artificial drainage in the area						OS			
Large area of surface depression						OS		FW	
On the coast area or lake shore						OS			
Reference rating	5	5	6	5	5	5	5	5	5
Observation rating									
Subsidence index									

C = Coal mine failure
L = Landslide
LS = Limestone solution
FA = Frost action
ES = Expansive soil
OS = Organic soil drainage
SP = Soil piping
FW = Fluid withdrawal
DS = Differential settlement

Compression ridges occur in the depression where the ground surface is subjected to concave bending and associated with shortening of the ground surface. Generally, compression ridges will be located in the central part of the depression. The ground cracks and compression ridges sometimes are not visible when they are located in the soil zone, especially when the surface is covered by vegetation. Figure 2 shows a ground crack that can be seen in the barren ground surface but can not be seen in the grassy surface. Figure 3 shows the direction of the ground crack change near the contact point of barren and grassy surfaces. Figure 4 shows a ground crack developed at the bottom and sidewall of a dug hole. The crack did not reach the surface. As the results of these three cases demonstrated that the stress at the tip of the crack in propagation was less than the soil cohesion and roots binding forces. Crack propagation was either stopped or changes its direction to the weaker part of the soil. In addition, a ground crack may have been developed in the subsurface and cannot reach the ground surface. Therefore, if the ground crack cannot be seen in the area it does not necessarily mean that a ground crack has not developed.

STRUCTURAL DAMAGE DUE TO SUBSIDENCE

Structural damages due to subsidence range from slight to very severe. Some structures may have a few hair-line cracks while others may have cracks a few inches wide. The damage severity is dependent upon (1) the types of ground surface deformation, (2) the type of stresses, (3) the type and size of structures, (4) the location of the structure with reference to the mine openings, (5) the material of the structures, and (6) the type of foundation or structure attached to the ground. For instance, structures attached firmly into the ground are likely affected more by the ground movements.

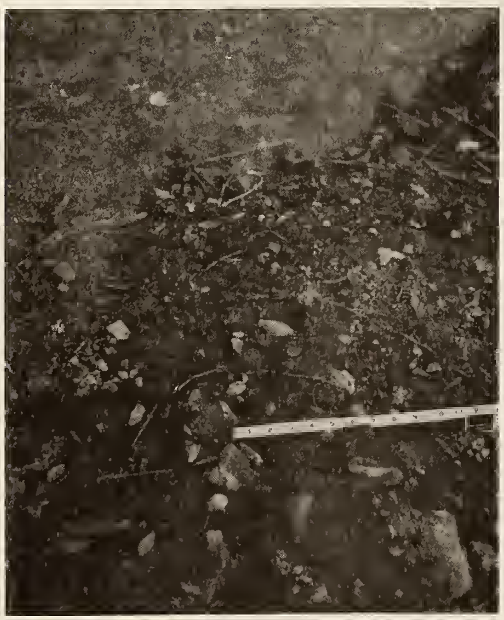


Fig. 2 Ground crack is stopped at the interface between barren and grassy surface shown by the arrow head. (Blacksville Case)

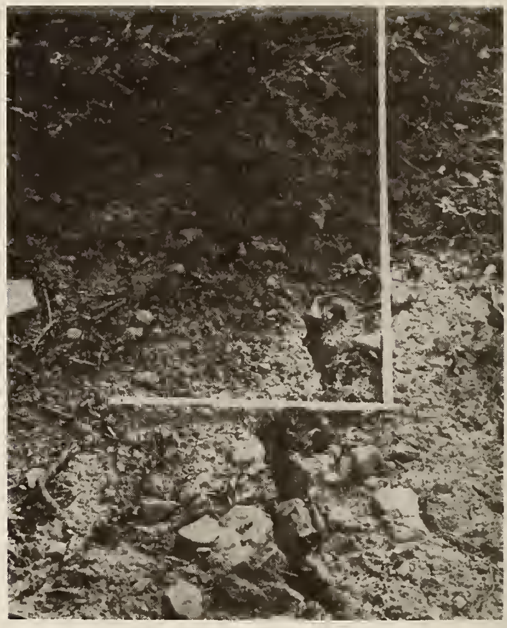


Fig. 3 The direction of ground crack changes near the intersection of barren and grassy surface shown by the arrow heads. (Blacksville Case)

Fig. 4 Ground cracks developed at the bottom and sidewalls of a dug hole but do not reach the surface. (Blacksville Case)

Figure 5 shows that the two-story wood frame house was laid on the ground surface and was not subjected to subsidence damage even when the surface subsided for 4 feet. This house was located almost in the center of a longwall panel and was laid on the ground surface without having basement or foundation attached into the ground. However, at the same panel another wood frame house with partial brick basement was subjected to damages (fig. 6), although the house was located close to the edge of panel and the surface subsided for only 1 foot.

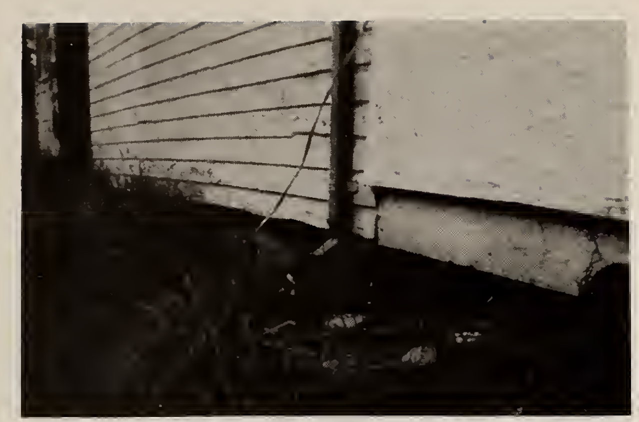
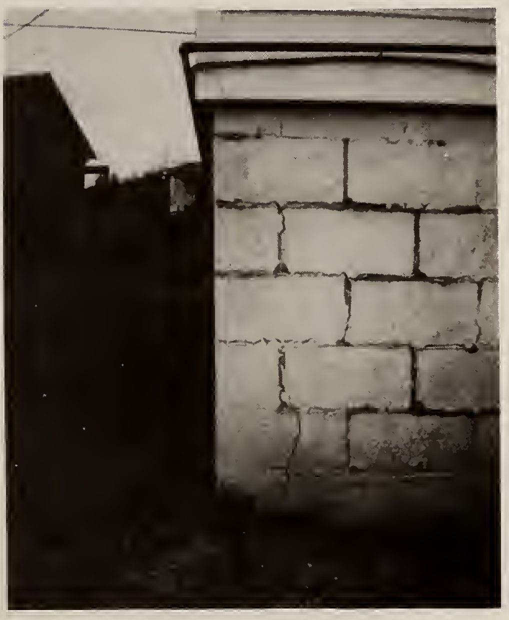


Fig. 5 Two-story wood frame house laid on the surface was not damaged

Fig. 6 A wood frame house with concrete block basement subjected to damage



Damages to buildings can be divided into functional (structural) and cosmetic (achitecture) damages. The major functional damages are misalignment of windows, doors and walls, slanting floor, leakage in the roof, and breakage of utility lines. This type of damages may impair the function and usage of the structure. The major cosmetic damages are cracks along the mortar lines on the exterior and interior walls, cracks on the stone facing and plaster, separation of siding and frames, and cracks on the floor. This type of damages are more annoying than dangerous. Both the functional and cosmetic damages can occur separately or simultaneously based on the level of the damage source. For instance, a low level of vibration due to traffic or industry may cause cosmetic damage. But a high level of vibration due to blasting or earthquick will cause not only cosmetic damage but also functional damage and some times even cause the collapse of the structure. If a building have a basement, the deformation of the building due to subsidence most likely will be initiated from the foundation or basement and propagate upward to the upper structure. The foundation or the basement is likely to suffer more severe damage than the rest of the building because the basement is directly subjected to the stresses. The damage are referred to the degree of the structure deformation not the repair cost.

RELATIONSHIP BETWEEN GROUND DAMAGES AND STRUCTURAL DAMAGES

Generally, the structural damages are associated with ground movements and the structures are assumed to move with the ground. However, there exists a resistance or friction, which is due to the weight of the strcture, between the structure and ground. Therefore, the ground movement cannot be entirely transmitted to the surface structures. Accordingly, several types of stresses such as axial, shear, and bending will be induced against the foundation of the structures or the structures directly. The axial stresses, either extension or compression, are caused by the horizontal movement. This type of stress will induce tensile and compressive damages to the structures. The shear stresses are caused by the friction between structure and ground. The bending stresses are caused by the vertical movement of the ground and will induce tilt and curvature damages to the structures.

As discussed earlier linear deformation is mainly due to nonuniform horizontal movement which will induce tensile and compressive damages to the structures. If a structure is subjected to tension the structure will be lengthened and open cracks will be induced along the joints and weak points such as the contact line between the windows, door frames and the walls. Figure 7 shows a typical example of tensile damage to concrete block walls. All the tensile cracks are uniformly developed along the brick faces and mortar lines because the brick faces and mortar lines are the weakest places on the brick wall. If a structure is subjected to compression the foundation walls will be buckled inward and induce horizontal cracks perpendicular to the direction of the compression along the mortar on the brick faces. Tensile cracks and buckled structures are the specific characteristics of tensile and compressive damages, respectively. Those characteristics can be used to identify the types of stresses which cause the damage to the structure.

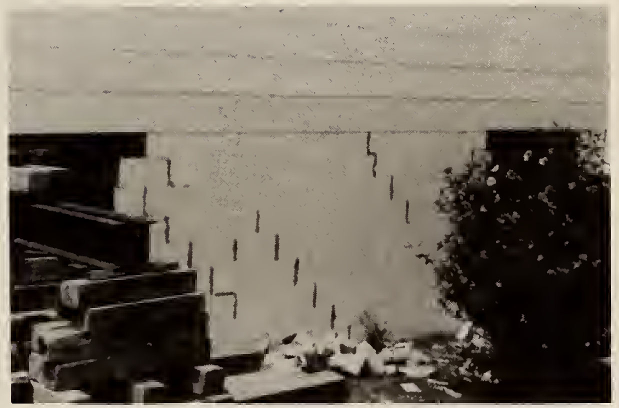


Fig. 7 Tensile cracks developed on the concrete block wall. (Peng and Hsiung, 1986; Jenkins Case)

When the ground slope changes, tilting will be induced on the structures. Tall structures with a small base, e.g., towers and chimneys are most sensitive to tilting. Natural ground slope will also affect the stability of the ground surface and structures when subsidence occurs. If the dip of a slope is consistent with the ground movement direction, the ground movement will be enhanced. On the other hand, when the dip of a slope is opposite from the ground movement direction, the ground movement will be reduced. In addition, a slope area may be an area prone to instability or landslide. Figure 8 shows the differential movement between the top of the soil and the top of the bedrock on a slope area after subsidence. The movement rate of the soil was about 0.07 in/month and was about 0.007 in/month for the bedrock during the study period. The movement of the soil was much faster than that of the bedrock. By the time the soil movement reaches its tertiary stage it may have caused additional damages to the structures located downslope.

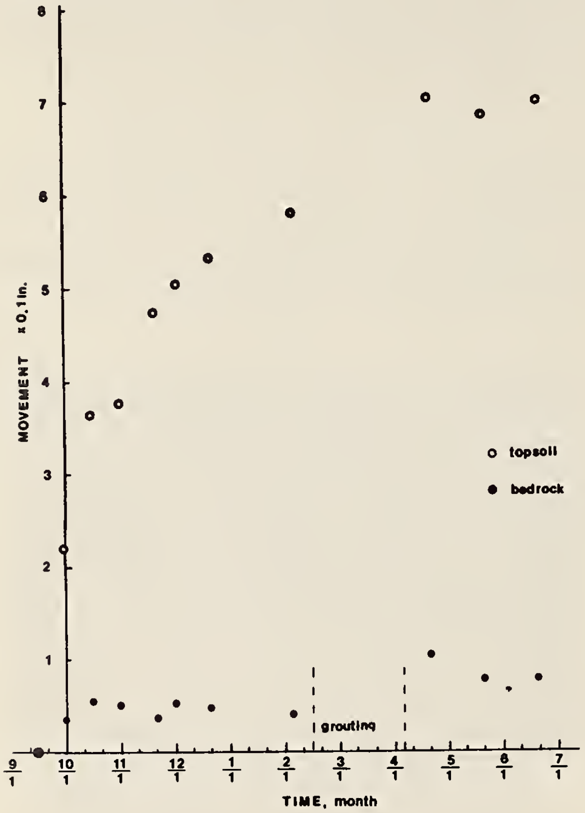


Fig. 8 Differential movement between top soil and top of the bedrock. (Peng and Hsiung, 1987; Johnston Case)

Depending on the location of the structure in the depression, the structure may be subjected to sagging or hogging damage. Sagging and hogging are two different types of ground curvatures which are caused by the differential settlement. Sagging is a negative or concave curvature. For structures located on the concave area, the lower portions of the structures are subjected to tension and the upper portions are subjected to compression. As a result, vertical cracks with wider gaps at the bottom occur at the window and door frames, on the walls, and at the wall joints. Figure 9 shows that the cracks on the wall in the bedrooms have wider gaps at the lower portion, i.e., an inversed v-shaped crack. This crack pattern indicates that the structure has been subjected to sagging. Generally, structures which are located at or near the central part of the depression will be subjected to sagging damage. Figure 10 shows the relative locations of the damaged houses which were subjected to sagging and the estimated subsidence depression. The most specific damage characteristics on the structure due to sagging are the concave bending and an inversed v-shaped crack.

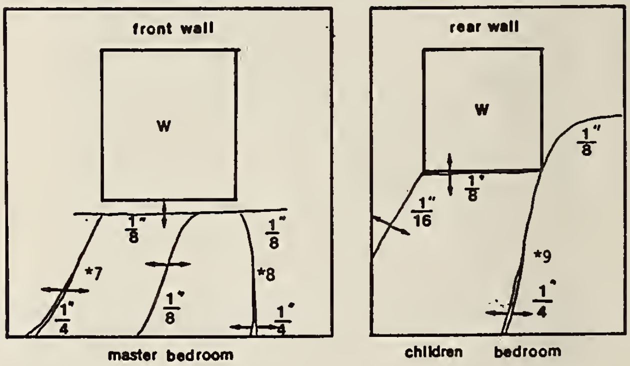
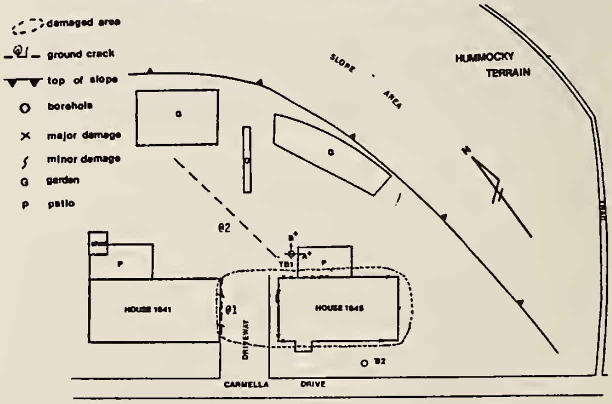


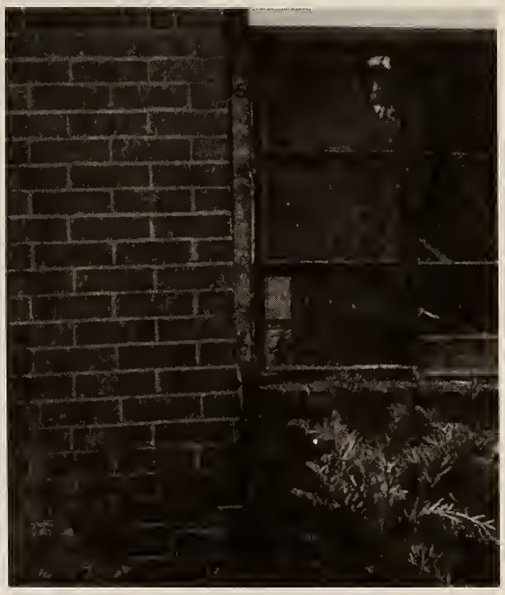
Fig. 9 Tensile cracks in the bedrooms due to sagging. (Peng et al, 1987; Valenson Case)

Fig. 10 Location of the damaged houses subjected to sagging and subsidence depression. (Peng et al., 1987; Valenson Case)



Hogging is a positive or convex curvature. For structures located in the convex area, the upper portions of structures are subjected to more severe stretching than the lower portions. As a result, vertical cracks with wider gaps are found at the top of the window and door frame, on the wall and at the wall joints. Figure 11 shows a crack with a wider gap at the upper portion, i.e. a v-shaped crack. This crack pattern indicates that the structure has been subjected to hogging. In general, structures located at the edges or the inflection point of the depression will be subjected to hogging damage. Figure 12 shows the relative location of the house which was subjected to hogging damage with respect to the estimated subsidence damage zone. The most specific damage characteristics on the structure due to hogging are the convex bending and v-shaped crack.

Fig. 11 **Wall separation along window frame subjected to hogging damage. (Peng and Hsiung, 1987; Fleming Case)**



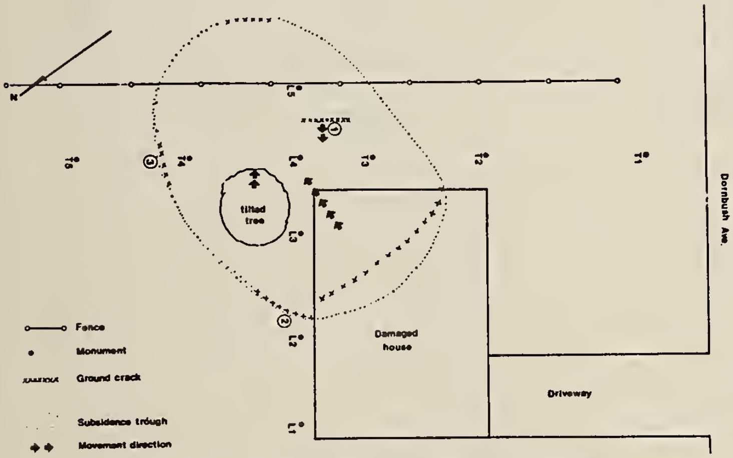


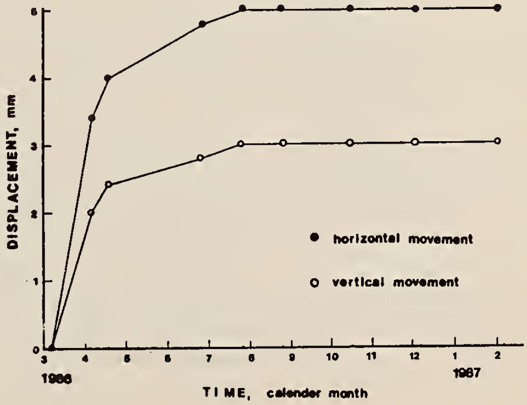
Fig. 12 Location of the damaged house which was subjected to hogging and the estimated subsidence depression. (Peng and Hsiung, 1987; Fleming Case)

INSTRUMENTATION AND RESULT

In order to have a better understanding of the underground conditions and the real cause of the damages, some instrumentation such as borehole TV camera, crackmeter, inclinometer and Sondex measurements should be conducted.

The 2-D tell-tale crackmeter and 3-D crackmeter can be installed at the strategic points on the exterior or interior walls to measure the changes of the crack width. The 2-D crackmeter is preferred because it can be installed and removed easily without leaving any trace on the walls. The measurement results from the crackmeter can be used to determine the movement direction and rate of movement. For instance, Figure 13 shows the horizontal and vertical measurement results using a 2-D crackmeter installed at the Valenson subsidence site (Peng, et al, 1987). It demonstrates that both the horizontal and vertical movements were significant in the early stages and that total movements were 5 mm and 3 mm, respectively, by July 23, 1987. After that date no movements were detected. The average horizontal movement was 0.036 mm/day and the average vertical movement was 0.022 mm/day.

Fig. 13 Results of the crackmeter measurement. (Peng et al., 1987; Valenson Case)



The borehole TV camera can be used to examine subsurface conditions such as fracturing of the strate, the condition of voids and underground openings. In order to get a complete picture of the strata fracturing and voids conditions in the boreholes, three types of viewing attachments to the camera head, e.g., downhole, radial close-up, and spotlight right angle can be employed. If the area is subjected to subsidence problems, the horizontal, vertical and diagonal fractures can be observed in the borehole in the strata above the mined out coal seam. In addition, cave-in and roof fall features and mine voids can also be observed by the borehole TV camera.

The inclinometer can be used to measure the horizontal ground movement by measuring the angle of inclination along its vertical axis of a grooved casing. The measurements are conducted along two axial directions perpendicular to each other. The measurement results can be used to determine the principal direction and magnitude of the ground movement. The principal movement direction is expected to point toward the epicenter or center of the subsidence basin in the mining-related cases. Figures 14 and 15 show the inclinometer data from the Valenson case (Peng, et al, 1987). They indicate that the history and magnitude of the ground movements can be used to determine the prinicipal direction of movement. For instance, before grouting operation started (October 16, 1987) the movements along A and B axes were continuously toward 180° i.e. negative direction. The principal ground movement direction was toward the epicenter. After November 19, 1987 (i.e., completion of the grouting) the movement along A axis almost stopped, especially the zone below the backfilled zone which was about 25 feet below surface. However, the movement along B axis did not stop and changed it direction to 0° or positive which was opposite to its original direction of movement. In addition, the backfilled zone had shown a significant amount of movement after the grouting. These phenomena indicate a potential problem of soil instability .

Fig. 14 Total displacement in A axis. (Peng et al., 1987; Valenson Case)

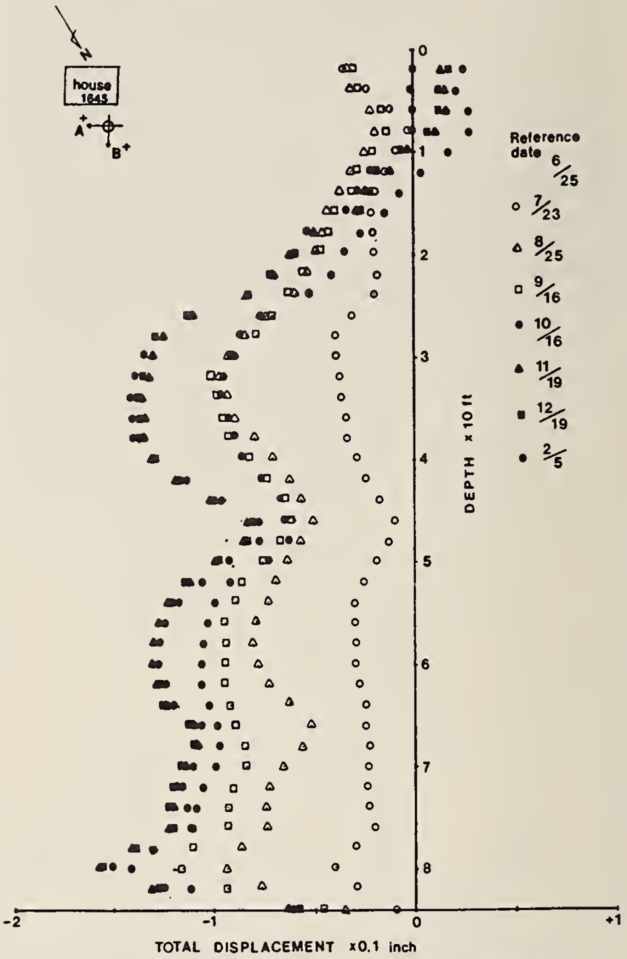
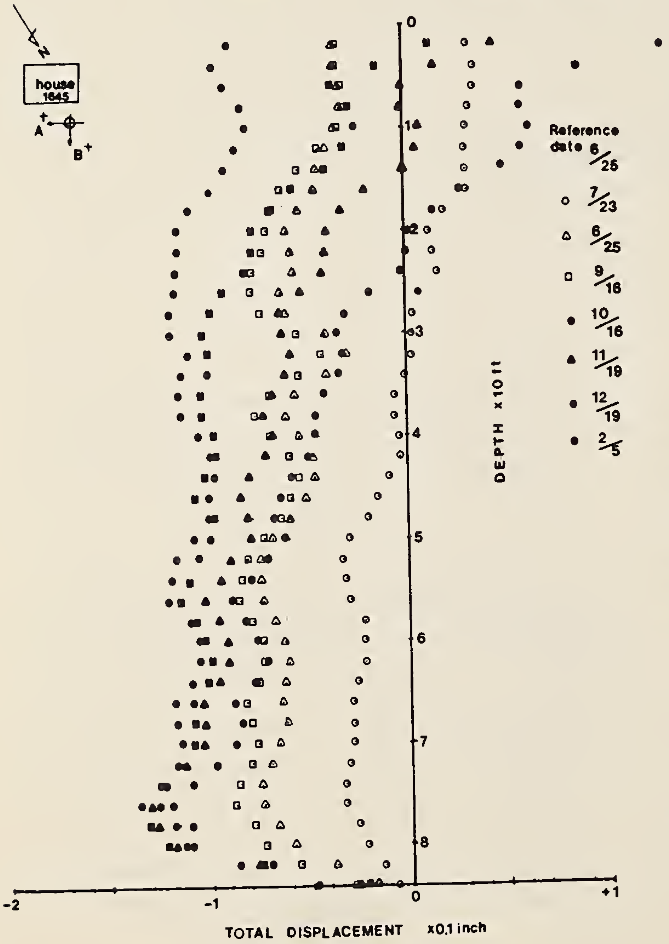
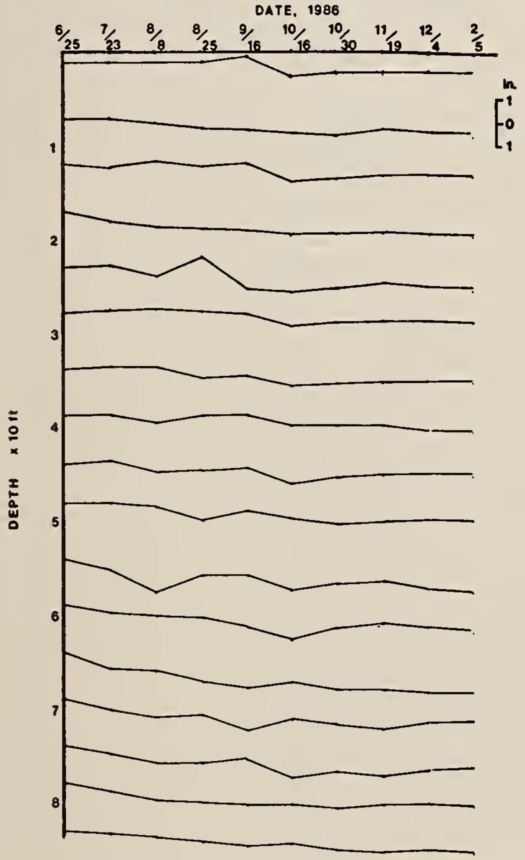


Fig. 15 Total displacement in B axis. (Peng et al., 1987, Valenson Case)



The Sondex settlement system is designed to measure subsurface vertical ground movements such as settlement or heave. A probe consists of a radio frequency oscillator and detector circuit will be lowered into the casing to locate the position of each sensing ring. The sensing rings is permanently mounted on the casing which is installed in the borehole. The vertical movement can be determined by the change in distance between rings which move with the subsurface strata. By interpreting the Sondex data, the rate of subsurface strata movement can be determined and the active formation can be located. Both items can be used to determine the causes of subsidence. For instance, if an area is subjected to subsidence all sensing rings will be subjected to movement. If an area is subjected to expansive soil problems, only those rings located in the soil zone will be affected. Figure 16 shows the measurement results from the Valenson site in which movement was about 1/2 to 1 inch for most of the rings. The movement for the top ring was about 1/2 inch and about 1 inch for the bottom ring. Since all the rings moved and bottom ones which were closer to the mined out coal seam moved more than the upper ones, it is most likely that the movement was induced by the abandoned mine failure.

Fig. 16 Vertical movement of the Sondex rings. (Peng et al., 1987; Valenson Case)



SUMMARY AND CONCLUSION

In this paper the approach and the procedures for abandoned mine lands subsidence research are described. The mechanisms of the possible causes, the damages to the ground surface and structures, and the relationship between the ground movement and structures has been explored. The methods and purposes of the instrumentations are discussed.

The most common damage to the ground surface are depressions, cave-in pits, ground cracks and compression ridges. There is no positive correlation between the dimension of the depression and its cause.

Due to different degree of stress concentration at the tip or at the end of the ground cracks, the direction of the cracks may be changed and the propagation of the ground cracks may be stopped. Therefore one may not be able to observe the ground cracks at the places where they are expected to be observed.

Structural damages can be divided into functional and cosmetic. Generally, functional damages are more severe than the cosmetic ones. Cosmetic damage can occur alone or may occur simultaneously with functional damage. Generally, the foundation or basement will be damaged more severely than its upperstructure. Structure damage is associated with the ground movement. Different types of ground movement will induce different types of damages to the ground surface and structures. Different locations of the structures in the depression or subsidence basin will be subjected to different types of deformation.

Sagging and hogging damages are due to the combination of linear and bending deformation. Most of the structural damages above abandoned mine lands are due to sagging or hogging but pure linear deformation is not common. The most specific damage characteristics on the structure due to sagging are the concave bending and reversed v-shaped crack. The convex bending and v-shaped crack are the specific damage characteristics due to hogging. By examining the damage pattern, the type of stresses and the damaged area can be located. Thses information can help people to identify the damage causes.

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MINE CONFIGURATION AND ITS RELATIONSHIP TO SURFACE SUBSIDENCE[1]

Jesse L. Craft and Thomas M. Crandall[2]

Abstract.--Careful evaluation of mine maps has been of considerable aid in understanding subsidence failure mechanisms above active and abandoned underground coal mines. This, in turn, aids the investigator in: (1) predicting what might happen in the future, and (2) designing proper corrective action to prevent additional subsidence events. Factors to be considered include accurate orientation of the mine map with surface features; pillar shape, size, alignment, and strength; percent coal extraction; overburden thickness and composition; location and orientation of barriers and unmined coal reserves; entry and haulageway size and alignment; water conditions in the mine; geologic structure; the presence of retreat mining in adjacent or nearby panels; and pillar alignment in association with retreated panels. Field investigations, including drilling programs, based on the evaluation of available mine maps have established clear relationships between surface effects of mine subsidence events and specific underground conditions causing the subsidence. These include: (1) coal barriers acting as fulcrum points causing massive surface cracks due to transfer of overburden loads (Graysville and Willow Bend, AL); (2) pillars incapable of supporting overburden loads (Graysville, AL); (3) alignment of pillars left to protect the surface, creating residual stress fields that fail in a catastrophic manner (Fairmont, WV); and (4) natural fracture systems, such as faults and joints, providing conduits for movement of unconsolidated sediments (piping) into the mine void and subsequently, movement of the surface (Arnold, PA and Shinnston, WV). These events have occurred with overburden thickness ranging from 20 ft to over 700 ft. Surface damage ranged from minor cracks and no vertical displacement to vertical displacement of 2.5 ft and cracks up to 6 ft wide and 200 ft deep.

INTRODUCTION

Underground mining creates a void system which disturbs the existing stress field established by natural processes. The overburden responds with the first cut into the coal and continues until the applied stress reaches a new equilibrium within the overburden. These stress changes result in deformation and displacement of the surrounding overburden material. The magnitude of the change takes place is controlled by the size of the cavity and the strength characteristics of the affected strata. Figure 1 is a simplified illustration of the forces acting on a stratigraphic section as a result of a mine void. The force vectors above the void are deflected toward the void proportionate to the distance from the center of the void. Below the coal seam an upward component of force also acts towards the center of the void. As the cavity increases in size, fractures develop in the overburden which may result in subsidence of the surface and sometimes heaving of the mine floor.

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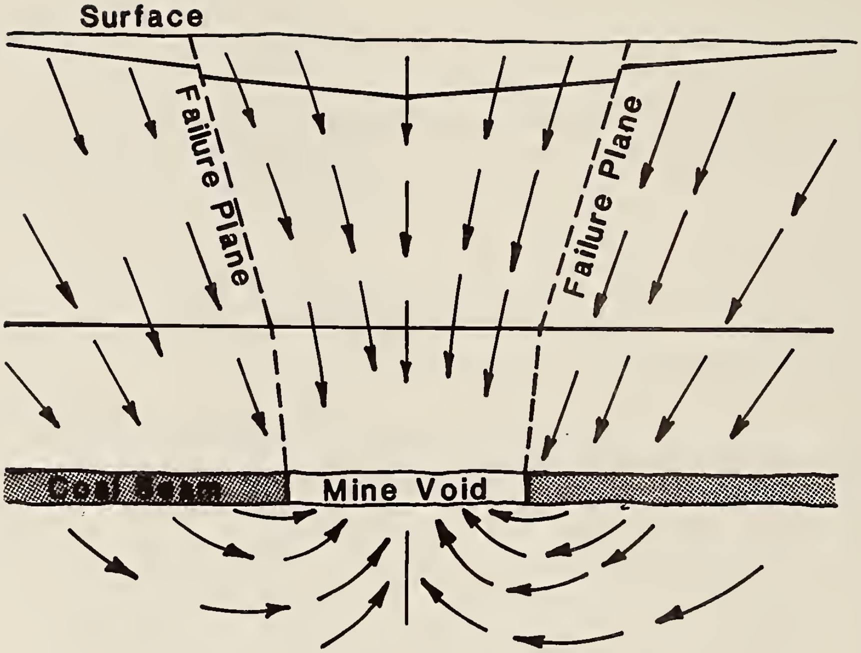


Figure 1.--Schematic representation of ground movement due to subsidence of overburden into a mine void (Grond, 1957).

Since 1979, the Office of Surface Mining Reclamation and Enforcement (OSMRE) has conducted 848 abandoned mine-related subsidence investigations in the 12 coal states east of the Mississippi River (table 1). These preliminary investigations established 572 situations as subsidence emergencies. Remedial action was implemented by OSMRE with project costs ranging from $200 (to fill a hole in a yard adjacent to a house), to approximately $3 million for ground stabilization in a large housing area. Overburden thicknesses above the mined-out areas ranged from less than 20 ft to over 700 ft.

Table 1.--Subsidence-related investigations and emergency projects conducted by OSMRE between October 1979 and July 1987.

STATE	FIELD INVESTIGATIONS	EMERGENCY PROJECTS
Alabama	11	5
Georgia	1	0
Illinois	35	32
Indiana	43	34
Kentucky	63	26
Maryland	1	0
Michigan	5	4
Ohio	82	45
Pennsylvania	505	360
Rhode Island	2	2
Virginia	5	3
West Virginia	95	61
TOTAL	848	572

In general, mine subsidence problems develop where post-mining pillar support systems and coal barriers ultimately fail. Many interrelated factors control when, where, and how failure will occur. These factors include:

a. Thickness of coal mined;

b. size, shape, and distribution of pillars and rooms;

c. percent extraction of coal;

d. thickness and physical characteristics of the overburden;

e. method of mining (e.g., longwall, shortwall, room and pillar, room and pillar with full or partial retreat);

f. dry or flooded conditions in the mine;

g. actual or potential level and degree of fracturing in overburden; and

h. mineralogy of overburden (e.g., clay minerals that swell when water is added, sulfide minerals that chemically and physically change in the presence of oxygen and moisture, and minerals that react with water to form new minerals).

Many of these factors can be determined through drilling, geologic mapping, or other technical data previously gathered for specific areas. However, data from mine maps are invaluable in determining subsidence failure mechanisms and provide information otherwise not available during a subsidence investigation. Once the failure mechanism has been determined, selection of the appropriate stabilization technique is possible.

USE AND DEVELOPMENT OF MINE MAPS

The importance of obtaining a mine map when investigating a surface disturbance believed to be associated with underground mining cannot be overemphasized. The mine map shows where mining has occurred and assists the operator in determining how to safely and effectively continue development to achieve maximum productivity. Mine maps identify entry, haulage, and escape systems. Mine maps also show the type of mining, coal barriers and reserves, and limits of underground mining activity up to the date of the map. They indicate the presence of retreat mining in adjacent or nearby panels and pillar alignment in association with retreated panels.

The investigator must, however, be aware of the following basic problems in working with archived mine maps:

a. The map may not represent the final mine configuration. There is always a time lag involved between mine surveying and the drafting of the information on the map. Many archived maps are obtained from sources other than the official files of the mine company (e.g., consulting companies and private individuals), and therefore may not be the final detailed map.

b. The scale of the map may be distorted due to the paper's stretching during copying or due to the photographic copying and reproduction process.

c. If the original print is not of very good quality, a reproduction may be very difficult to read. This is especially true of maps reproduced from microfilm.

MINE MAP ORIENTATION

The key to using a mine map in a subsidence investigation is accurate orientation of the map with surface features. This can be done in several ways. The simplest is to identify the coordinates used for control during the underground mine survey and to re-establish those controls on accurate surface maps. On OSMRE projects where survey control was re-established, drilling was 98 percent successful in confirming mine geometry and intersecting desired drilling targets.

When the control points no longer exist, it is not possible to re-establish the original survey control associated with the mine map. However, many surface features that existed at the time of the mining, such as air shafts, houses, railroads, roads, and property lines, are represented on the mine map. When these features can be located on the surface, a new coordinate system can be generated and used to orient surface and mine maps drawn to the same scale. On OSMRE projects where this technique was applied by a professional surveyor, drilling was about 90 percent successful in verifying mine geometry.

Despite re-establishment of survey control, drilling targets are sometimes missed. An example of this occurrence was in Belleville, IL, where OSMRE conducted a large subsidence stabilization project (The Canterbury Manor Project). A mine map was available (scale: 1 inch equals 100 ft), and OSMRE secured aerial photography to produce a topographic map at the same scale. The coordinate system used on the mine map appeared to be the township and range survey lines; therefore, the two maps were oriented using the local township and range corners established by the city. When initial drilling in the area indicated the orientation of the mine map was incorrect, the mine map was reoriented with the surface based upon the intersection of voids and pillars defined by eight drill holes. A total of 77 vertical and 23 angle construction holes were eventually drilled for this project. The map orientation phase of the project saved at least $43,000 in drilling costs, since 22 holes would have intercepted coal pillars and been unsuitable for remedial grouting if the original map orientation had been used to locate the holes.

The required adjustment of the surface mine map orientation was 5 degrees west of north - the magnetic declination of the Belleville area in 1903 when the mine map was prepared. It was concluded that the mine survey was done with a magnetic compass. The project clearly demonstrated that proper map orientation paid off in the overall success of a project. Drilling costs were reduced and adequate support ensured.

EVALUATION OF MINE MAP INFORMATION

Surface subsidence associated with past or present mining activity can occur through many processes taking place in the mine. Some of these processes can be interpreted directly from the mine map, and others only inferred from results of other aspects of a site investigation. Map interpretation of failure causes is possible when roof collapse, pillar crushing, or failure associated with reserves left in place occurs. Sometimes, evaluation of the mine map indicates adequate coal was left to protect the surface, and the subsidence is associated with other factors. Such failure mechanisms, identified by OSMRE investigations, are piping of unconsolidated sediments into the mine through fractures in the overburden; mine closure resulting from squeeze of underclays, middle clays, and roof clays; and disaggregation of highly broken overburden due to flooding of the mine. Because these factors are not related directly to the mining configuration, it is more difficult to identify these failure mechanisms using a mine map. Information indicating the potential for the latter types of events is more likely found by investigative drilling then through mine map interpretation.

Subsidence Types and Their Relationship to Mine Plan

The surface expression of subsidence associated with rock failure in the mine is often characteristic of how the failure occurred. OSMRE has identified three major types of subsidence events. These subsidence types are defined on the basis of the surface expression of the subsided area.

Pit or "Pothole" Subsidence

This type of subsidence is usually associated with roof failure under shallow overburden or piping of unconsolidated sediments into the mine through subsidence-induced or naturally occuring fractures. The size and character of the hole in this case is related to the physical character of the unconsolidated sediments being piped into the mine. When the entire overburden is rock, a shallow depression will develop. The depression is usually circular in shape and conforms approximately to the size of the collapsed room in the mine. Pit subsidence is often marked by rows of depressed areas corresponding to the room and pillar distribution in the mine. Once the fall occurs and propagates to the surface, the ground is usually stable and no further subsidence takes place unless the broken overburden is disturbed by water.

Sag Subsidence

Sag subsidence is generally associated with crushing of pillars or squeezing of underclay, middleclay, or top clay. The focus of subsidence is directly over the crushed pillars or displaced clay. Depression outlines are circular to oval in shape and range from a couple of hundred to a thousand feet in width and length. The size of the depressed area is determined by a domino-type failure of additional pillars which can take place following the initial failure. Ground movements associated with sag subsidence can extend over a long period of time because of the gradual transfer of overburden loads to adjacent pillars. High volumes of methane gas are commonly associated with the subsided area when pillar crushing is associated with the subsidence event.

Cantilever Beam Subsidence

This type of subsidence occurs where a portion of the overburden is adequately supported along the edge of a panel and failure of pillars occur within the panel. The overburden contains a cohesive rock unit that does not easily fracture, but functions as a lever. The overburden above the support section (fulcrum) bends as the pillar area fails, lowering the cohesive rock unit until the rock fails and cracks occur at the surface directly above the edge of the fulcrum block. This type of subsidence can affect large areas. The surface expression of the subsidence forms long, continuous, straight-line fractures that parallel barrier pillars or unmined coal reserves. Overburden thickness is usually greater than 300 ft. Crushing of the coal occurs along the edge of the support block, and methane gas may be encountered during the drilling program. However, drilling into the mine workings usually intercepts open voids close to the support block. Open voids usually exist because the roof is supported by the block of coal, since only the outer edge actually crushes.

This type of subsidence has also been found in the shadow area between two mines. It is especially pronounced in areas where an active pillar retreat mine is separated by a common barrier from an older retreat-mined operation.

Other

There are other frequent site-specific situations that cause surface damage. Such situations include flooding or dewatering of the mine, which causes adjustments of rock materials especially in retreat portions of the mine and/or failure of a bridged or hanging roof. These types of events can sometimes be recognized from information presented on the mine map. When flooding of the mine occurs, surface subsidence can recur due to breakdown of rock immersed in water and movements of the disaggregate rock away from the failure area. Dewatering causes a realignment of pillars and roof especially in retreat mined areas with corresponding overburden movements.

CASE STUDIES

The following case studies involve several of the above subsidence mechanisms and illustrate how mine maps were utilized to identify them.

Bridged Roof/Pillar Failure - Fairmont, WV

The Country Club Road project in Fairmont, WV is an example of subsidence associated with a mine plan that was designed to protect a surface structure. The site is located along a main access road (Country Club Road) to a rural farming area outside of Fairmont. The mining company left support under Country Club Road in the area where pillar retreat mining was occurring (fig. 2). The road meanders to conform with surface topography and the unmined pillar lines are consequently offset so as to parallel the center of Country Club Road.

The subsidence incident began when residents of the home marked "1" on the mine map (fig. 2) heard a loud "explosion" followed by shaking of their homes. Cracks developed in the interior walls of the structure and continued to enlarge over the next few months until completion of an OSMRE stabilization project. Cracks also began to develop in other houses along Country Club Road following the initial subsidence event. An OSMRE emergency drilling program found that the overburden thickness averaged 275 ft and the mine area was flooded. The pillars between houses "1" and "2", and the smaller pillars between houses "3" and "5" were crushed.

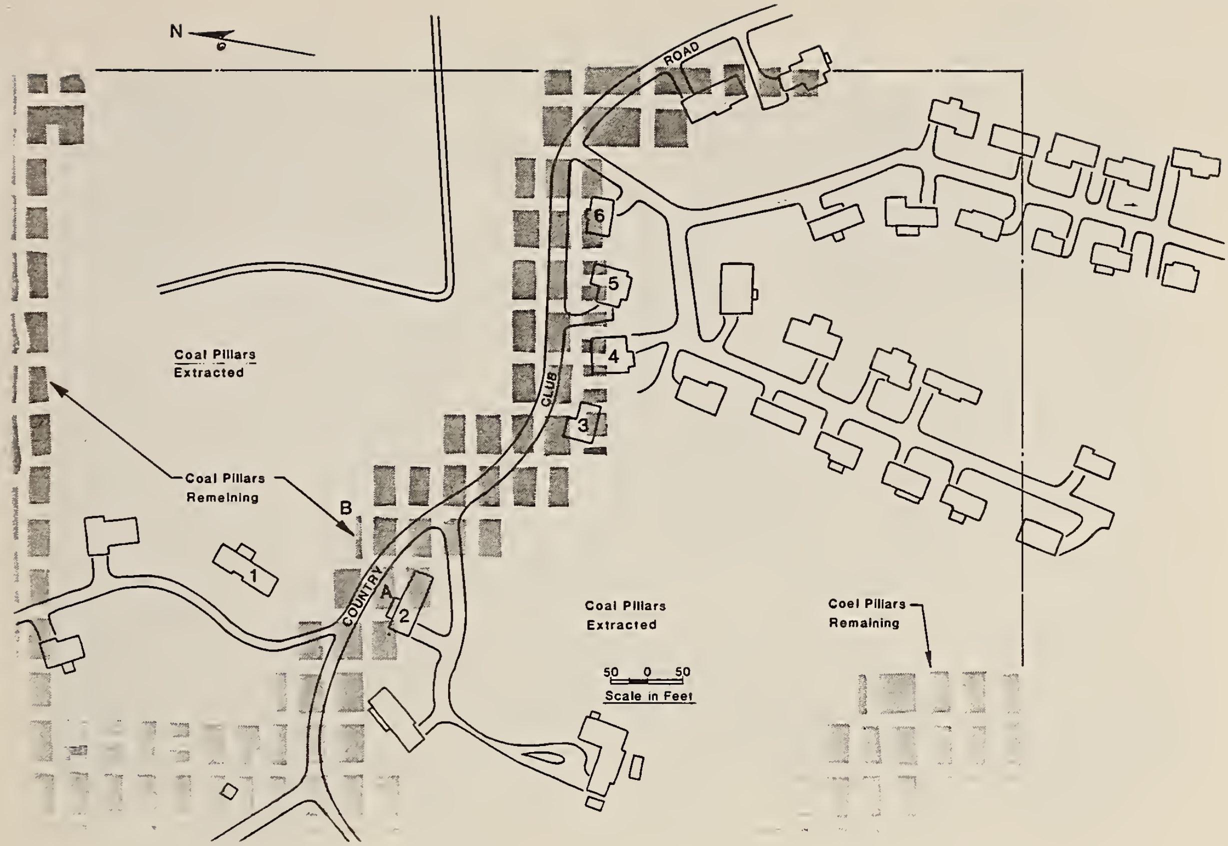


Figure 2.--Surface structures and mine map, Country Club Road Subsidence Project, Fairmont, WV.

Based on the drilling evidence and the configuration of the pillars shown on the mine map, it appears the initial failure is attributable to a "bridged roof" between the offset of the pillars at point "A" and crushing of the thin pillar at point "B" (fig. 2). When the bridged roof failed, it caused failure of the pillars between house "1" and "2" and triggered adjustments of the overburden all along the pillar line. These adjustments resulted in additional pillar crushing, further consolidation or settlement in the already collapsed retreat area adjacent to the pillars, and, thus, considerable damage to the surface structures.

Remedial measures on this project were twofold. A rock anchor system was installed at House "1" to stabilize the steep hillside (Mates et al. 1986). Cement grout was injected to fill mine voids and stabilize the existing pillars within the subsidence zone.

Cantilever Beam Failure - Graysville and Willow Bend, AL

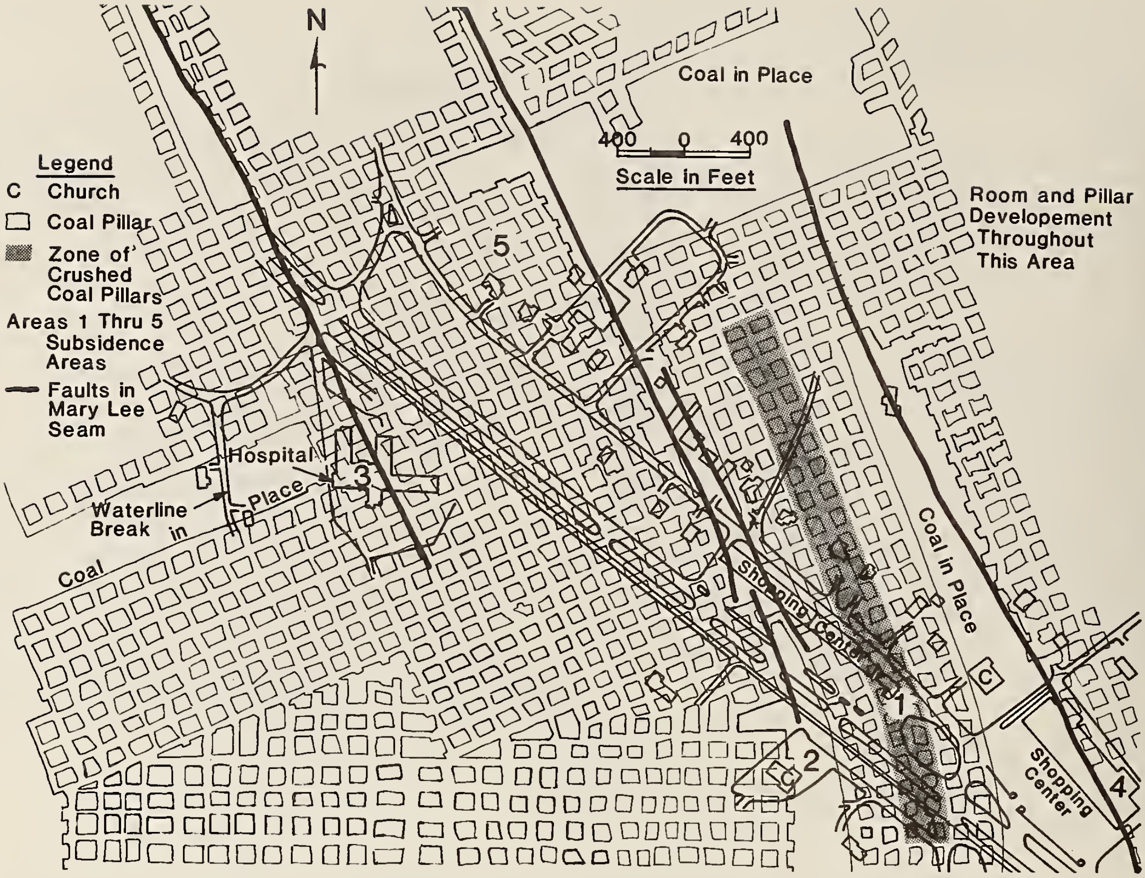
Subsidence events in the Graysville, AL area illustrate a series of complex subsidence events which through the evaluation of mine configuration were determined to be an example of cantilever beam controlled subsidence. In early 1980, a subsidence event affecting approximately 14 homes, a shopping center, and a service station was investigated by the State of Alabama and OSMRE.

In mid-1980, the U.S. Bureau of Mines, under a cooperative agreement with OSMRE, conducted an in-depth investigation of the site and concluded that the affected area actually encompassed a total of 42 homes, 2 shopping centers, 2 service stations, 2 churches, and a hospital (fig. 3). The areas damaged by surface subsidence were some distance from each other, yet all were related to similar mining and geologic conditions (Morrison et al. 1987).

The Pratt (Blossburg B Mine) and Mary Lee (Flat Top Mine) Seams were mined at depths of 200 and 700 ft, respectively. Of the five distinct subsidence areas identified in figure 3, Areas 1 and 5 were of an emergency nature, and remedial stabilization measures were implemented (Morrison et al. 1987).

The geotechnical investigation focused on Area 1 (fig. 4). The Pratt Seam mine map shows no mining in the most disturbed part of the area. Examination of mine maps in the Mary Lee Seam revealed that mine development in Area 1 (fig. 3) was controlled by faulting, and that reported subsidence events were clustered along the coal left in place along and between the fault zones.

Exploratory drilling confirmed that no mining had occurred in the Pratt Seam. The drilling also established that the overburden was fractured below the Pratt Seam; therefore, the subsidence was initiated by the mining in the Mary Lee Seam.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C Church
Coal Pillar
Zone of Crushed Coal Pillars
Areas 1 Thru 5 Subsidence Areas
Faults in Mary Lee Seam
Room and Pillar Developement Throughout This Area
5
Hospital
3
Waterline Break
Coal in Place
Shopping Center
Coal in Place
C
1
2
C
Shopping Center
4

Figure 3.--Surface features and mine map of the Mary Lee Seam, Graysville Subsidence Project, Graysville, AL.

Pillar strength calculations (Morrison et al. 1987) indicated that the pillars within the fault block (table 2) have a safety factor of 1.2 and could carry the overburden load when the entire block of coal contained within the gravity fault block is involved in the support system. However, the calculation of the support within the panel yields a safety factor of 0.6 which indicates the pillars have marginal strength to carry the loads. Pillar strength estimates also indicated that panels on both sides of the faulted area have a safety factor of only 1.0. However, the area to the west of the fault block would be more prone to settlement/subsidence than the area to the east because of the narrower barrier rib and the interrupted panel design (fig. 3).

It was concluded that the barriers associated with the faults, and subjacent to the hospital, are acting much like a pair of fulcrum blocks, with a lever beam extending out over the large panels in both directions. The subsidence associated with Area 1 is the result of the development of a strain arch between the two fault barriers, as the overburden settled over the large panels. Subsidence occurred when horizontal friction at the center of the strain arch between the two fault barriers equaled zero, causing vertical loading and crushing of the center pillars.

Table 2.--Pillar crush analysis for Graysville Subsidence Project Mary Lee Seam (depth, 700 ft) (Morrison et al. 1987).

Pillar location	Extraction (%)	Crush depth (ft)	safety factor
Within the fault block	32	806	1.2
Panel beside fault area	50	710	1.0
Within the panel	62	454	0.6

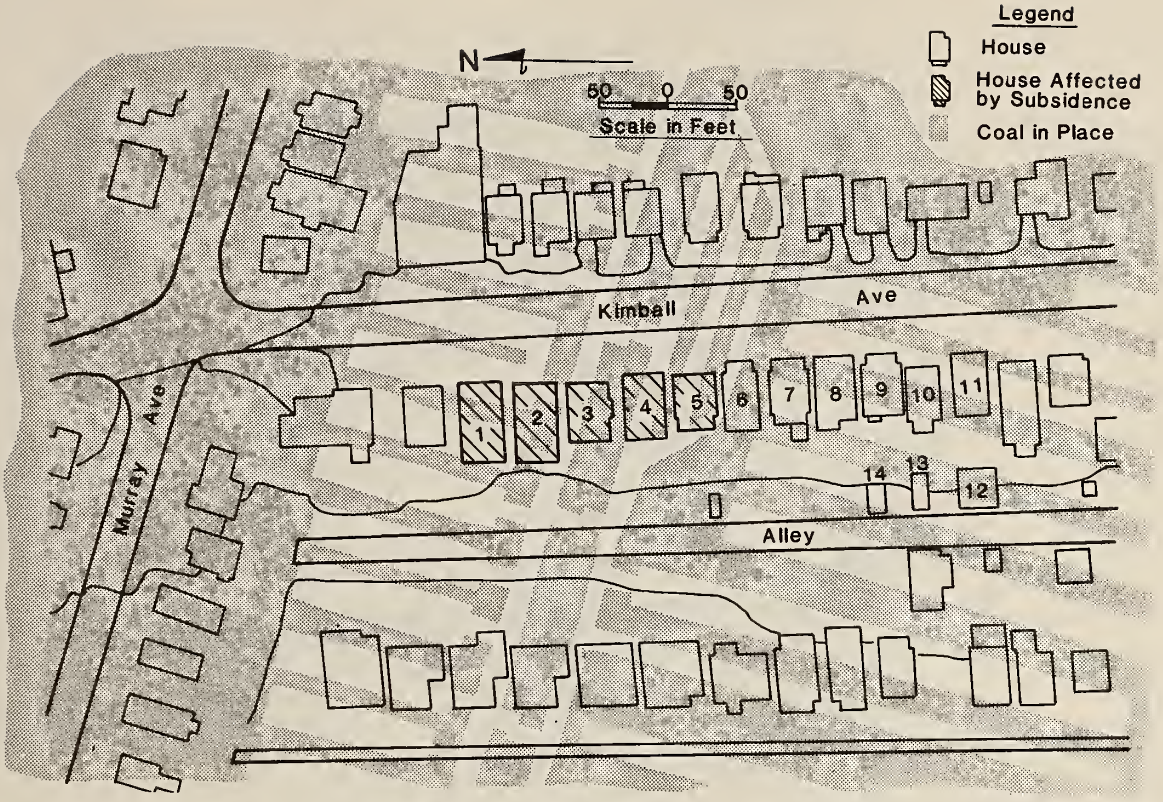

Figure 4.--Surface structures and mine map, Arnold-New Kensington Project, Arnold, PA.

Surface cracks which developed in Areas 2, 3, and 4 were the expression of the tension release over the fulcrums and exhibited very little vertical displacement. Subsidence at Area 5 was most probably the result of failure of the pillar support system due to the redistributed loads created by the settlement taking place over the region. The settlement taking place over the large panels could be due to compression of the "middleman" clay members within the Mary Lee Seam, crushing of the pillars, or a combination of both.

Large volumes of methane gas were encountered during the drilling program and are believed to be the result of pillar crushing within the panel. Gas analyses from boreholes outside the panel between the two faults showed only a trace of methane. The gas trapped within the area between the two faults had to be released during a degasification program because the gas was reaching the surface through the subsidence cracks and threatening public safety and property. Three bleeder holes installed by OSMRE were venting over 300,000 ft^3 of methane/day when installed in 1983. The pressure equilibrium is presently being maintained with one bleeder hole.

Another example of a cantilever beam failure ocurred at the Willow Bend project in Hueytown, AL, where evaluation of the mine map and use of a drilling program established that mine roof collapse and pillar crushing had taken place on the edge of the barrier pillars supporting main entries and unmined reserves. Surface stabilization consisted of building a series of concrete support columns extending from the coal barriers. Field monitoring has shown that the movement stopped after the point support columns were installed.

Piping Through Fracture Systems - Arnold-New Kensington, PA, and Shinnston, WV

The Arnold-New Kensington Subsidence project in Arnold, PA is an example of surface subsidence associated with an underground mine that was not caused by mine roof or pillar failure. Initial evaluation of the mine map and the subsequent investigative drilling program determined that sufficient coal was left in the mine to support the surface, yet, the subsidence event destroyed one house and extensively damaged four others. This case study illustrates how OSMRE has utilized mine maps in conjunction with other maps and information obtained during the investigation to establish the true cause of the problem.

Figure 4 is a mine map which also includes surface topography and location of homes. The map shows large coal pillars along a haulageway directly beneath the properties. Drilling authenticated the presence of the pillars and identified 6-ft open voids. Earlier drilling by the Pennsylvania Department of Environmental Resources encountered approximately 3 ft of light brown silt partially filling the void under the alley behind the center house (fig. 4, House 3). This material strongly resembled the Quaternary age Carmichaels Formation, a 90-ft- thick terrace

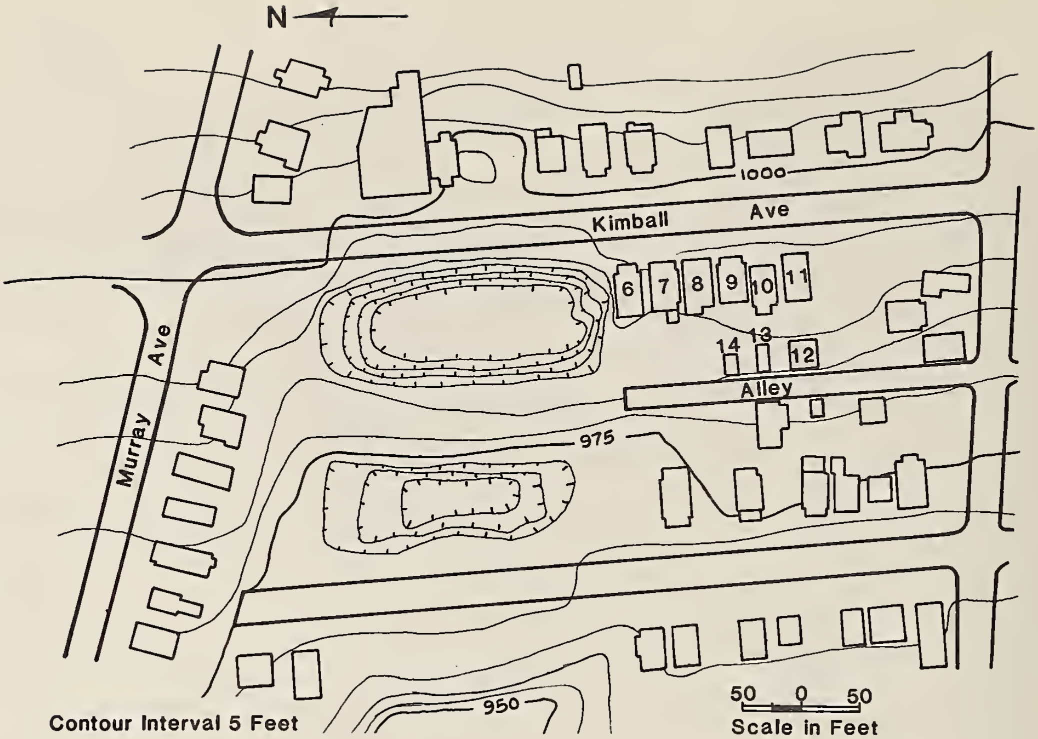

Figure 5.--Topography and urban development in 1952, Arnold-New Kensington Subsidence Project.

deposit in this area. Local citizens indicated that the subsidence area was an old sand pit that had been filled in with household trash and brush and covered over. A topographic map constructed from 1952 aerial photography showed the sand pits (fig. 5). Drilling also confirmed the character of the fill in these pits. There was some suggestion that the problem was related to this fill area. This fill, however, did not explain the magnitude of the subsidence occurring at the site. At this point in the investigation, there was no evidence of failure in the mine, yet a major depression was continuing to develop on the surface.

OSMRE subsequently implemented a drilling program in and around the problem area. The drilling in the immediate vicinity of the subsidence area identified a normal fault situated directly below the houses (fig. 6) with a vertical throw of 10 ft. The drilling program also established that the coal seam was 260 ft below the surface, and the base of the Carmichaels Formation was 90 ft below the surface. Silts of the Carmichaels Formation were recovered in one core hole at a depth of 245 ft. Borros anchors were installed both in front of and behind the houses at various depths to attempt to identify the zone of movement within the terrace deposits. Inclinometer casing was also installed in front of and behind the houses to measure movement in the fill and the underlying Carmichaels Formation.

Information from Pennsylvania Department of Environmental Resources drilling was plotted on a map and the Carmichaels Formation/bedrock contact was contoured (fig. 7). Also plotted on this map is the trace of the near-vertical fault as defined by the OSMRE drilling program. This map indicates a pre-Carmichaels stream valley located at the center point of the surface depression and a nick point (waterfall) on the fault line. The sum of information indicated the development of surface geomorphology was fault-controlled with a strong possibility of valley stress release jointing exposed at the pre-Carmichaels interface.

Information obtained from the Borros anchors and the inclinometer readings established that movement was taking place throughout the Carmichaels Formation, but not in the bedrock. Water level readings from the inclinometer casing indicated a depression in the water table directly over the projected location of the fault at the Carmichaels/bedrock interface (fig. 8). The drilling established the presence of Carmichaels-like sediments in the mine and in the overburden 15 ft above the mine roof.

From the available information, it was concluded that surface subsidence was caused by the piping of silt from the Carmichaels Formation downward through open valley stress release fractures associated with the normal fault. A grouting program was implemented to seal the Carmichaels/bedrock interface and surface movement subsequently stopped.

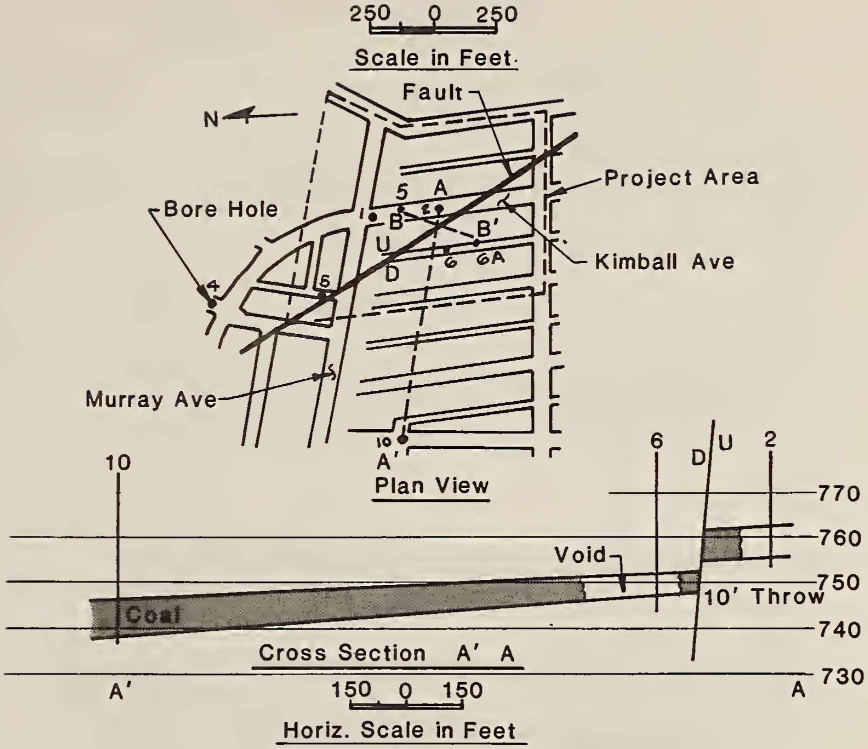
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Figure 6.--Plan map and cross-section A-A, Arnold-New Kensington Subsidence Project.

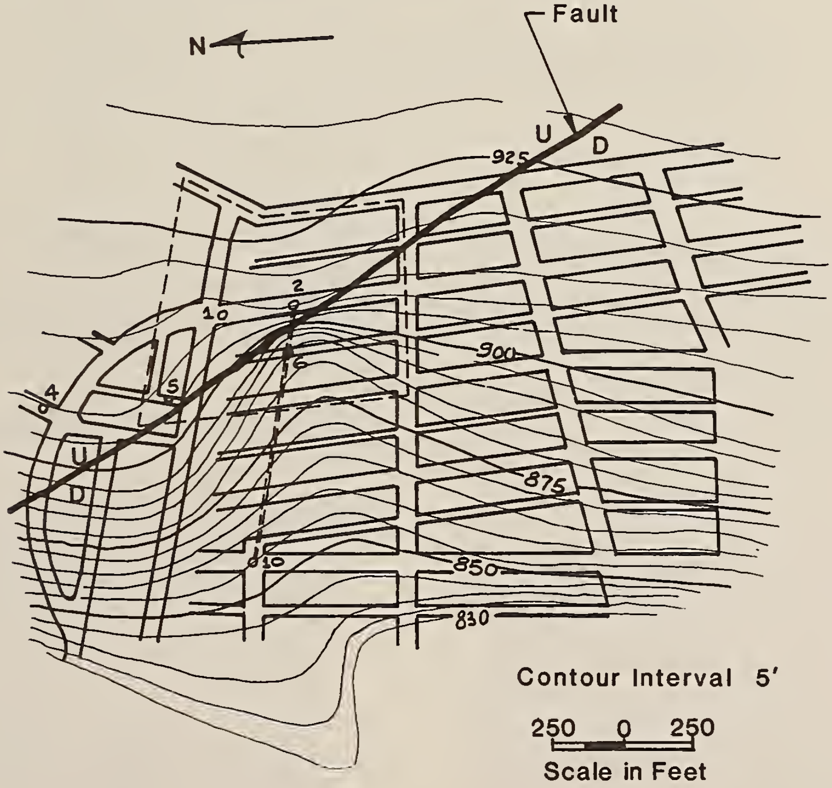
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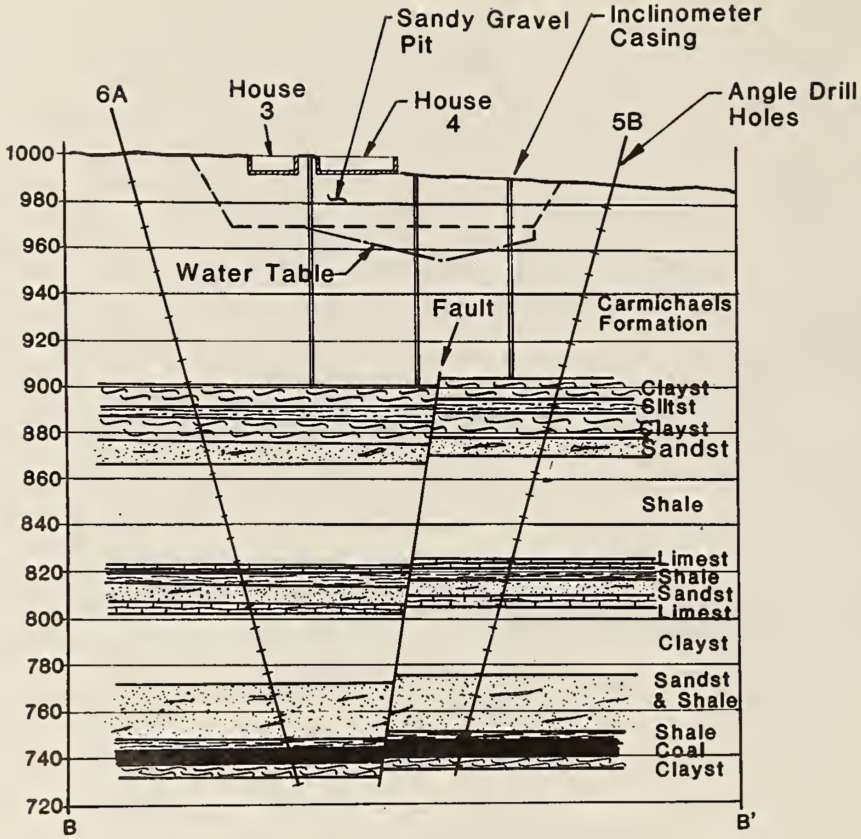
Figure 7.--Bedrock topography underlying the Carmichaels Formation as reconstructed from drilling records, Arnold-New Kensington Subsidence Project (note nick point developed at the fault line).


Sandy Gravel Pit
Inclinometer Casing
6A
House 3
House 4
5B
Angle Drill Holes
1000
980
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780
760
740
720
Water Table
Fault
Carmichaels Formation
Clayst
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Clayst
Sandst
Shale
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Figure 8.--Cross-section B-B, Arnold-New Kensington Subsidence Project. Cross section location shown on figure 6.

This phenomenon was also observed in an abandoned mine in Shinnston, WV where a thick fan of the Carmichaels Formation was flowing out of an open joint in the bedrock. In this case, the flow was taking place during mining as the fan was partially confined behind a crib wall built by the miners. Over the years piping had created depressions on the surface that homeowners had been filling as they developed.

CONCLUSIONS

Knowledge of the mine configuration is essential to a subsidence investigation and the interpretation of the subsidence mechanism(s). The investigator should obtain all available mine maps in the subsiding area and establish survey control points to accurately tie the mine map to the surface. Once established and confirmed by drilling, mine geometry and the exploratory drilling data can be evaluated to determine the failure mechanism which resulted in the surface disturbance. Only after the failure mechanism has been determined, can an effective stabilization program be implemented.

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AN ANALYSIS OF EXTREME DANGER PROBLEMS ASSOCIATED WITH SUBSIDENCE OF ABANDONED COAL MINE LANDS IN SOUTHWESTERN INDIANA [1]

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Abstract -- Subsidence from Abandoned Coal Mines in Indiana has resulted in 23 sites which present an Extreme Danger to individuals. The source of information for this paper is the National Inventory Update of Abandoned Mine Lands for Indiana. Three types of subsidence occur in Indiana: pit, trough, and shaft. Pit subsidence has caused the vast majority of Extreme Danger Subsidence Problems. The average depth of subsidence is 105 ft. and 78% of these problems are in areas where the overburden is less than 165 ft. thick. Topographically, 15 of the 23 sites are located in lowland areas. The mining of the Springfield and Seelyville Coal Seams accounts for more than 50% of the problems. Both seams usually have poor quality roofs of shale and poor quality clay floor materials; the Seelyville Seam has a particularly mobile underclay. Early mining techniques of irregular room configuration and insufficient pillar support have had a profound influence on subsidence. The average year that mine production began is 1909, when many of these early mining techniques were still being employed in Indiana. The outlook for subsidence in Indiana is that the problems will persist and their numbers may increase as the years put more stress on the older mines.

INTRODUCTION

Coal mining in Indiana had its beginnings in 1812 when horse-drawn scrapers were used to gain access to the shallow coal seams. In the early 1850's shaft mining became more widespread. Underground mine production rose steadily and first peaked around 1918. All of this coal mining is not without its continued impact on the environment and individuals. Any time an area has been undermined there is the possibility of subsidence. The timing of this event is unpredictable, but "the mine is going to come down eventually and everything is going to have to adjust" (Carey 1984).

It is estimated that 10,900 acres of potential subsidence threaten urban areas alone in Indiana (Gray and Bruhn 1984). The focus of this paper is the Extreme Danger Problems associated with subsidence in Indiana. The connotation here is danger to people, but damage to property like houses and farmland is also considered as it presents an Extreme Danger to the occupants and farmers.

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[1] Paper presented at the 1988 Mine Drainage and Surface Mine Reclamation Conference sponsored by the American Society for Surface Mining and Reclamation and the U.S. Department of the Interior (Bureau of Mines and Office of Surface Mining Reclamation and Enforcement), April 17-22, 1988, Pittsburgh, PA.

RESEARCH METHODOLOGY

The data in this study are a result of a research grant from the Indiana Department of Natural Resource, Division of Reclamation and the Office of Surface Mining to conduct the National Inventory Update for Indiana. Fieldwork and interviews were a necessity in the compilation of information required on the update forms. Many sites were visited repeatedly as problems in the area changed. Additional sources of information include, but were not limited to, Preliminary Coal Maps for each county, Coal Investigation Maps for selected quadrangles, Mined maps for each topographic quadrangle, Indiana Geological Survey-Coal Section files, Indiana Department of Natural Resources-Division of Reclamation files, and newspaper and trade magazine articles.

FACTORS INFLUENCING SUBSIDENCE

Coal Geology

Fourteen coal seams have been rather extensively mined in Indiana. The Extreme Danger Subsidence Problems were associated with only seven of these coal seams. The characteristics of each have a profound effect upon the subsidence problems. The seam occupying the lowest geological position is the Pinnick Seam. Generally, the seam is thin, about 2.1 ft. thick, and rather hard to trace (Shaver et al. 1970). The roof is carbonaceous shale or massive ferruginous sandstone with an underclay floor. The second seam, the Upper Block Coal ranges in thickness from 1.5 to 5 ft. thick. The roof is usually thick-bedded shale; however, in some areas it is a soft shale overlain by massive sandstone. The floor is a hard carbonaceous underclay that becomes "plastic" when moist. The third seam, the Minshall-Buffaloville Coal is irregular in extent and thickness. The roof is clayey to silty shale and in some places it is a black sheety shale. The floor is a gray plastic underclay that may be nearly 3 ft. thick (Shaver et al. 1970). The fourth seam, the Seelyville Coal averages 6 ft. in thickness, but ranges from 1.5 to 11 ft. thick. The roof is either a gray, silty, carbonaceous shale or a brown to gray massive, friable carbonaceous sandstone. The floor is a gray underclay that may be plastic and shaley in places. This fireclay floor is a "very mobile layer" (Karpiniski 1938) that caused past active mining difficulties. The fifth seam, the Survant Coal has several shale partings that may be 20 to 30 ft. thick. The roof is usually sandstone or gray shale. The sixth seam, the Springfield Coal is the most widespread in Indiana and maintains a relatively constant thickness over these areas. The roof is usually a gray shale, but may also be sandstone or clay. The floor is a silty clay, shale, or sandstone. The final seam, the Hymera Coal ranges in thickness from 0.5 to 11 ft. The roof and floor are usually shale.

Mining Techniques and Characteristics

The most common means of coal extraction in Indiana was the Room and Pillar method. The specifics of this method vary with the characteristics of the coal seam and the time when mining occurred. Early room and pillar mining in Indiana was rather irregular (fig.1). This wandering was a failure to create or stick to a regular mining plan. This was typical of mines in this study from the late 1800's to the middle 1920's. The rooms were wide, 12 to 30 ft. The entries were narrow, only 6 to 8 ft. wide. The depth of the room varied from 165 to 600 ft. This irregular pattern resulted in many pillars of odd shapes and sizes. Many of these pillars are too narrow to support the overburden indefinitely.

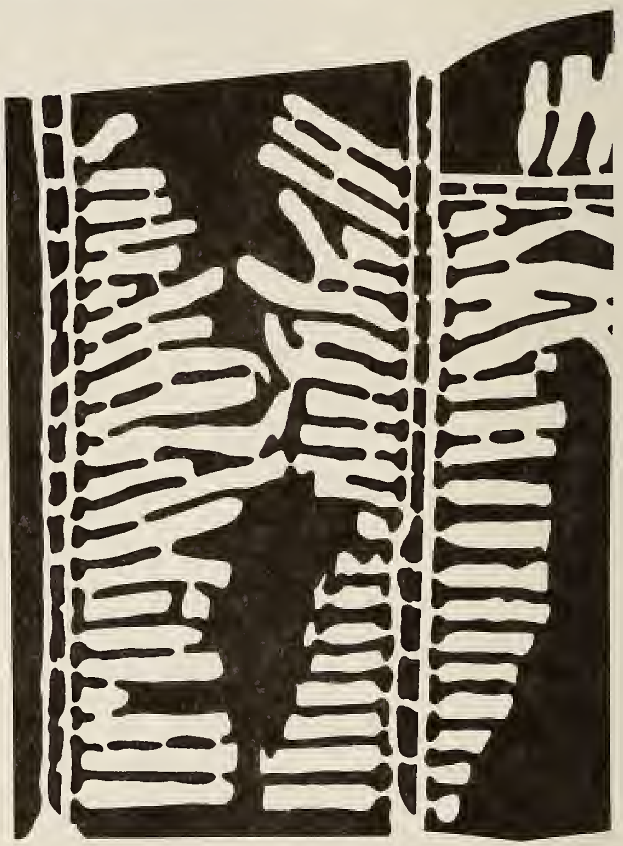

Figure 1.--Early room & Pillar method (Andros 1915).

Later the patterns of removal were more systematic (fig.2), and there was more concern over continuing mine stability. At this time the room width remained the same, the entries were twice as wide, and the length of the rooms was

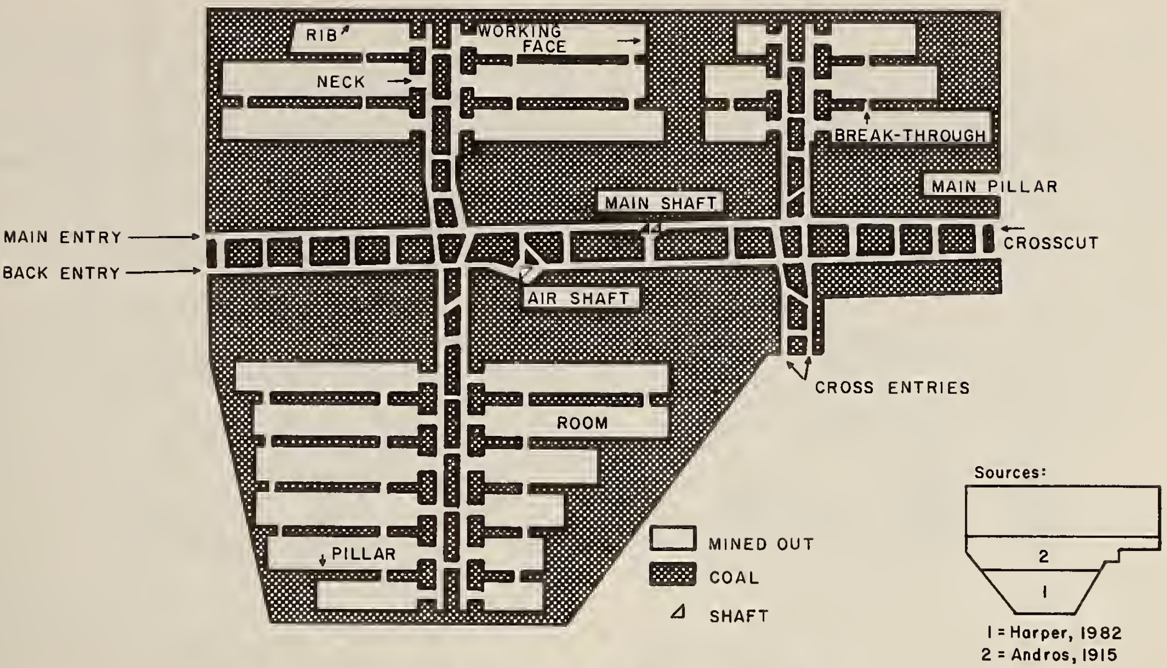

Figure 2.--Systematic room & pillar method.

much shorter - 175 to 400 ft. However, with this systematic removal of coal the pillars were consistently 6 to 23 ft wide.

In the early mines, roof supports were chiefly timbers and rather narrow coal pillars. Timbers could be quite closely spaced, but the average life of timbers in an active mine was rather short. Later metal and concrete replaced wood, however the conditions in some mines were quite corrosive (Karpiniski 1938). Since the early 1950's, roof bolting has been employed along with coal pillars.

Roof stability was affected by the types of overlying materials and the presence of any discontinuity. Faults, joints, horsebacks, or rolls all degraded the roof quality. Many of these are noted on the coal mine maps for the subsidence sites. Another common practice that affects the roof stability is "robbing pillars". This gouging of coal from the pillars was unsafe in active mining and adds greatly to the subsidence potential in abandoned mines. It was particularly unsafe when, as in some cases, this practice occurred at and around the bottom of the shaft (Harper 1982).

Some problems incurred during active mining give insight as to the types of problems that influence subsidence in the study area. In the Saxton Mine, there were notations on the mine maps of numerous areas of "bad top" (Harper 1982). There were also roof rolls and extensive clay veins and slips that thwarted efforts to adhere to mine plans. In several old mines in Clay County, coal and clay were extracted from the same mine; this gives evidence of the type of floor and roof materials which were present.

The Saxton Mine extended beneath the Wabash River. There was a very real lack of a solid overburden thickness. Roof falls and "water breaks" were common (Harper 1982). This lack of sufficient overburden thickness when mining beneath a river was also quite common in southern Indiana along the Patoka River. Sometimes distances beneath the river and the underlying coal were as little as 10 ft.

OCCURRENCES OF SUBSIDENCE

There are three main types of subsidence in Indiana; pit, trough, and shaft. Pit subsidence is responsible for more of the Extreme Danger Problems in Indiana than trough or shaft subsidence. Each of these three types of subsidence have specific movements which separate them from each other however, Eventual erosion, is a type of movement which accentuates each of these subsidence problems.

Typically, pit subsidence occurs from the failure of the roof (fig.3). The result is an opening from 6 to 8 ft. deep and 2 to 40 ft. in diameter (Dumontelle 1981). The main movement, at least initially, is vertical. In the Eastern United States, pit subsidence usually occurs where mines are less than 100 ft. deep and in Pennsylvania, most pit subsidence is found where the mine overburden is less than 50 ft. (Gray and Bruhn 1984). Areas where the mine is

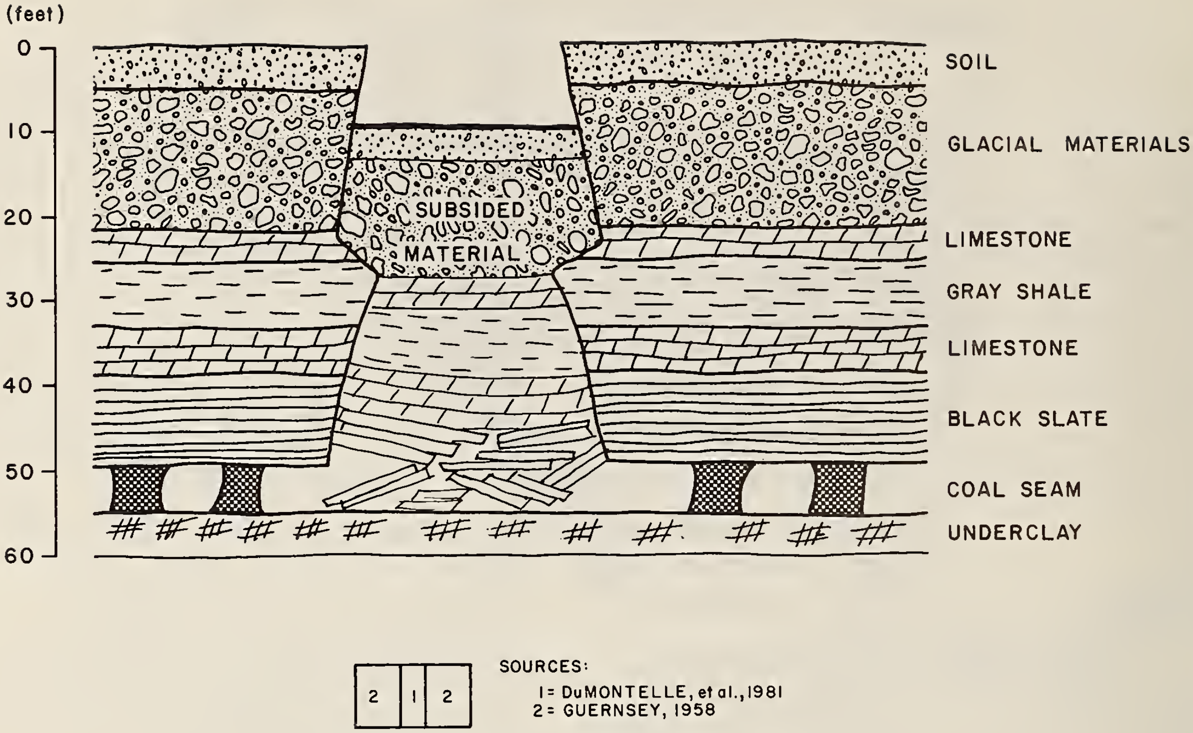
(feet)
0
10
20
30
40
50
60
SOIL
GLACIAL MATERIALS
LIMESTONE
GRAY SHALE
LIMESTONE
BLACK SLATE
COAL SEAM
UNDERCLAY
SUBSIDED MATERIAL
2
1
2
SOURCES:
1= DuMONTELLE, et al., 1981
2= GUERNSEY, 1958

Figure 3.--Idealized pit subsidence

deeper than 150 to 165 ft. experience decreased frequencies of subsidence occurrence (DuMontelle 1981, Harper 1981). Pit subsidence usually occurs over rooms and entries resulting in a surface reflection of the mining pattern.

The second type of subsidence is trough. Usually, this is a gradual disintegration of the pillars or squeezing of floor materials into the mine voids. The disintegration and squeezing may also occur simultaneously (fig.4). Troughs may occur in areas of mining at any depth, but most frequently associated with deeper mines than those where pit subsidence occurs. Troughs are usually 2 to 4 ft. deep and cover larger areas than pit sub-

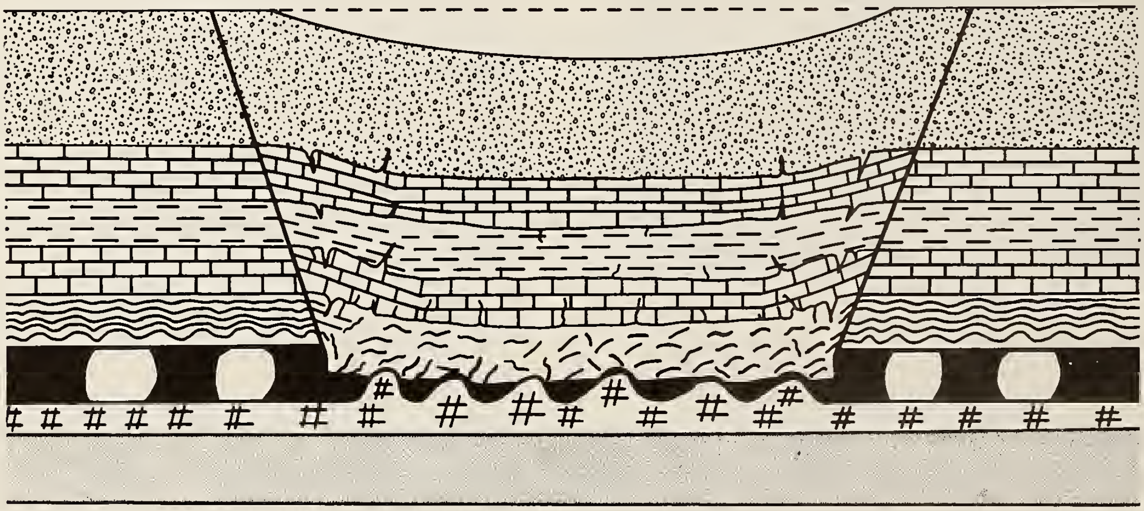

Figure 4.--Idealized trough subsidence (modified from DuMontelle 1981).

sidence. The movements are both vertical and horizontal (DuMontelle 1981) as the whole area is depressed. The horizontal areas may extend over a broader area than is undermined. For a 160-ft-deep mine, the area affected may be 75 ft. beyond the mined out areas (DuMontelle 1981). This is an important point as many individual homeowners in Indiana feel that they and their property are safe if the mine does not extend beneath their house.

The third type of subsidence is associated with the shaft itself. This is commonly associated with older mines, especially those in Clay County (Harper 1982). The older shafts were not supported well when active mining was occurring. Frequently the added weight of the buildings and equipment near the shaft was not considered in the required support. Decades later the supports fail and erosion widens the original shaft opening (fig.5). New subsidence sites in Indiana "will pose continuous problems because they are a result of collapsing shafts and tunnels" (Honea and Baxter 1983). In the Western United States, subsidence occurs around mine shafts. This subsidence is similar in appearance to pit subsidence, except the pits are much deeper (Dunrud 1984). Similar conditions to these are present in Indiana.

RESULTS

Extreme Danger Situations

A total of 77 occurrences of subsidence present an Extreme Danger to individuals in certain areas in Indiana. Some examples of the recent problems in Indiana are noted here. One air shaft subsided to a depth of 20 ft. in a corn field, just a few weeks after harvest. A child in Clay County was in the backyard playing when the ground beneath his feet gave way and he dropped down 15 ft. Near that same site, a road collapsed on Christmas. Several sites are near the foundations of houses, one is near a trailor, and others are located in backyards.

Some subsidence is active. One trough has increased in size by approximately 20% in the last 2 years. One shaft has increased in size from the original size of a 10 by 15 ft. rectangular shaft to an area 75 ft. in diameter in the last 15 years. This particular shaft contains a combine, three old cars, and 60 years worth of household garbage. Most of the occurrences average 20 ft. in diameter and have an average estimated depth of 25 ft. One trough is 225 ft. long, 100 ft. wide, and 30 ft. deep. The Miami #1 Mine, an area of active sub-

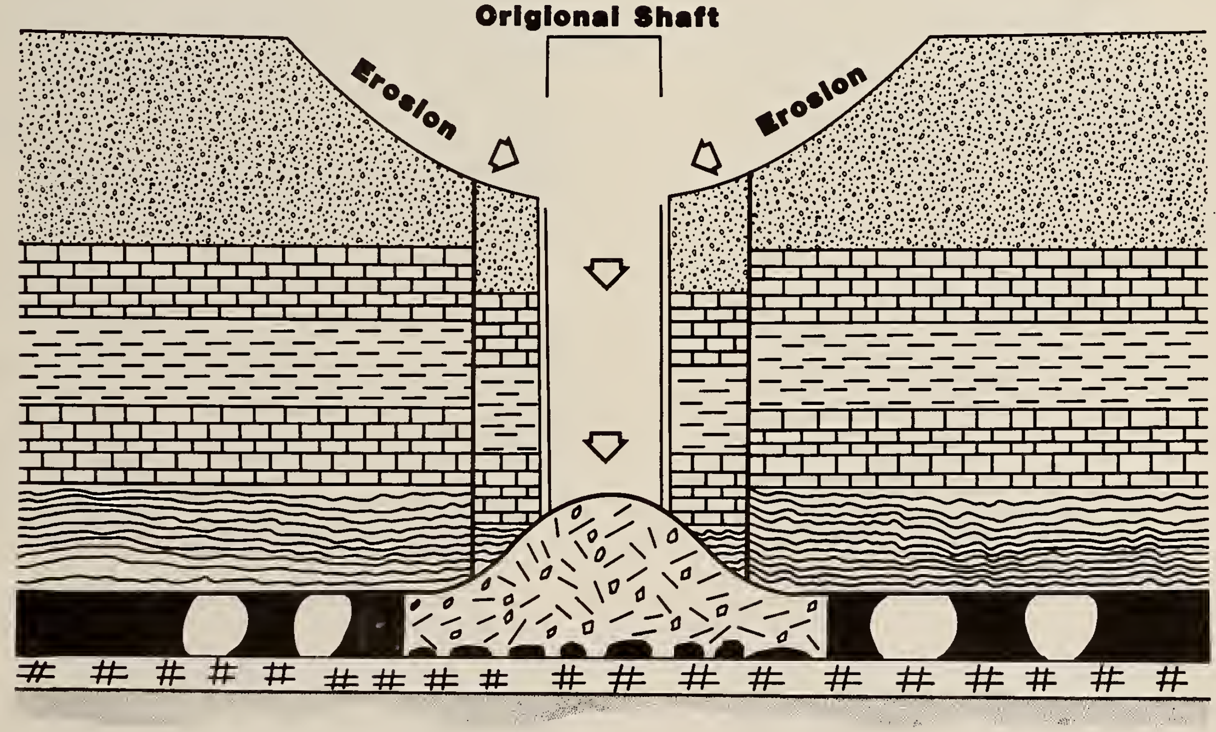

Figure 5.--Idealized shaft subsidence (modified from Dunrud 1984).

sidence near two houses, is typical of the small old mines. Medium size trough areas are particularly in evidence in the Clay County area, where robbing pillars was routinely practiced.

Discussion

There are 23 sites in Indiana where subsidence presents an Extreme Danger to people (fig.6). Clay, Green, Vigo, and Warrick are the four counties with 74% of the sites. Most had more than one occurrence of subsidence. There are 77 individual occurrences associated with the 23 sites of Extreme Danger Problems.

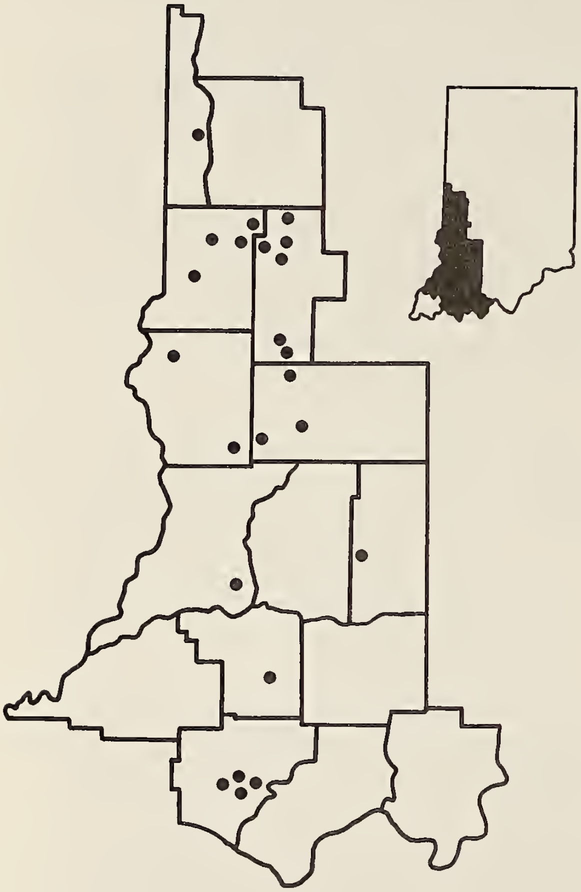

Figure 6.--Twenty-three Subsidence Sites in Indiana.

In addition to these, there are at least 200 acres affected by subsidence that present a danger problem or are affecting the land surface in less-inhabited areas. It should also be noted that many subsidence problems that demand immediate action fall under the auspices of the Office of Surface Mining Emergency Program.

The seams where most of the problems occur are the Springfield with 8, Seelyville 5, Survant 4 and Hymera 3. The three remaining seams have one problem site each. The Seelyville Coal seems to have an inordinately higher percentage of subsidence occurrence than appears to be warranted given its relatively low percentage of coal production.

In Indiana, the Extreme Danger Problems were mainly associated with pit subsidence. There were 70 occurrences of pit subsidence, 3 of trough, and 4 of shaft subsidence. Most of the subsidence occurred in areas of shallow overburden. Areas less than 165 ft deep accounted for 78% of the problems. This was reduced to 70% in areas less than 100 ft deep and 43% in areas less than 50 ft deep. The depths ranged from 25 ft to 550 ft; the average depth was 105.6 ft.

Topographically, 15 of these mines were located in lowland areas, 6 in upland areas, and 1 on a floodplain. One site was in the Wisconsin glaciation region, 16 were in the Illinoian glacial areas, and the remaining 6 were in the non-glaciated areas of Indiana.

There were strong relationships between the total number of Extreme Danger Problems in Indiana and the beginning and ending years of coal production (Elbert 1987). There were more problems associated with the older mines. The beginning year of production was more characteristic of the types of mining techniques employed at the mine than did the ending year of production. Usually the methods and techniques used in mining the coal at a particular mine did not change much over the duration of production. Also, many mines with Extreme Danger Problems were relatively shortlived with 30% remaining in operation less than 5 years, and 50% less than 10 years (Elbert 1987).

Of the 23 subsidence sites, the range of the beginning year of production was 1884 to 1950. Five began production before 1900, and twenty began before 1920. The average year production began was 1909. The years production ended ranged from 1897 to 1960. Seven ended production before 1920, and sixteen had ended production by 1930. The average year production ended was 1923.

CONCLUSIONS

The subsidence problems in this study have occurred from abandoned mines which were abandoned between 1897 and 1960. Most of these mines were abandoned in the early 1920's. More than 50% of the areas were undermined 60 years ago, and 40% were undermined 30 years ago (Harper 1982). In Indiana, mines associated with all

Extreme Danger Problems were abandoned approximately 5 to 7 years behind the production peaks for coal in the state of Indiana (Elbert 1987). Therefore, since peak underground production occurred in 1918 and the mean of the date of abandonment is 1923, it would be expected that subsidence in Indiana will continue at least at the present rate, if not increase.

The most prevalent type of coal removal in underground mining in Indiana was the room and pillar method. When coal has been extracted, there is always the possibility that subsidence can occur. More research into all types of subsidence problems in Indiana would facilitate the prediction of future subsidence.

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SODIUM SILICATE GROUT TECHNOLOGY FOR EFFECTIVE STABILIZATION OF ABANDONED FLOODED MINES[1]

Richard H. Reifsnyder, Robert A. Brennan and John F. Peters[2]

Abstract -- The construction of support systems to prevent the subsidence of abandoned, flooded mines is difficult and costly. Existing technology, which relies on the placement of fly ash/cement grouts to form supporting columns underwater, is inadequate since the grout quickly becomes diluted by the surrounding water. This results in a separation of the grout components and loss of all self-supporting characteristics of the mix. A new technique has been developed in which the grout stream passes through and reacts with a curtain of sodium silicate during placement to form a calcium silicate gel barrier on the grout surface that limits dilution of the mix by water. A field-scale mine simulation study funded by the Office of Surface Mining, Reclamation and Enforcement has shown that this technique enhances the underwater formation of grout columns with a high angle of repose. Grout columns built using this technique have an average angle of repose 5.5 times greater than control samples and are on the average 48% stronger after 28 days. This process also prevents the separation of grout components and reduces the raw material cost for column construction by a factor of 10.

INTRODUCTION

The subsidence of abandoned coal mines has become an increasingly important problem due to the potential for property damage and loss of life for residents in the affected areas. The stabilization of these sites is of major concern to the Office of Surface Mining, Reclamation and Enforcement and State agencies because the onset of subsidence can be unpredictable and usually requires an immediate and effective response to alleviate the situation. Over the past few years there have been over 50 emergency subsidence events per year, on the average, involving flooded mines and requiring corrective action. The majority of these events affect only a small area, but if not stabilized quickly and effectively the subsidence can spread, creating hazardous conditions in adjacent areas.

Normally the stabilization of collapsing mines can be remedied easily using the current technology available, but where the site is flooded, this technology can be ineffective and economically unfeasible. The method of mine stabilization currently being used involves the injection of large volumes of a cementitious grout into

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the mine cavity to partially fill the void and support the weight of the overburden. In most cases the grout mixture used consists of varying proportions of Portland cement and fly ash. Ratios of fly ash to cement range between 5:1 and 9:1 and the ratios are selected based on compressive strength requirements and raw material cost. This grout is injected into the mine via boreholes and usually tremied into place to produce columns or separate piles of grout to support the mine roof. Later the entire void may be filled with a fly ash slurry or mine refuse to complete the stabilization.

Under flooded conditions, this stabilization technique has been found to be ineffective. Building a column that will provide roof contact using a minimum amount of grout requires a low-slump, high-viscosity mixture. When a grout of this type comes in contact with water, the mix starts to become diluted as water passes into the grout matrix. Dilution reduces the viscosity and self supporting properties of the grout, preventing the formation of a column and resulting in a pile exhibiting a low angle of repose. Also, as the grout mix passes through the water, the fly ash and cement components of the grout tend to segregate due to particle size and density differences. Fly ash is separated out of the mix and is washed away or left suspended in the water reducing the volume of the grout that eventually will harden. In many cases, the water within the mine is moving, causing the grout pile to erode before setting is achieved and in some cases actually moving the grout away from the site requiring stabilization.

A new technique has been developed that allows for proper placement of a cementitious grout under water without loss of strength or slump value. This technique relies on passing the grout through a curtain of sodium silicate during placement. On contact, the sodium silicate reacts with the surface of the grout stream, forming a calcium silicate gel that acts as a barrier to prevent water from penetrating into the grout mass and diluting the mix. Silicate also accelerates the set of the grout, allowing it to gain strength quickly and preventing erosion while a column is being formed. Thus, a column is formed using a minimum of material. Previous laboratory work done indicates that grout columns built in this manner display higher angles of repose, faster set times, and higher final compressive strengths than control samples.

In 1987 a series of mine simulation studies were conducted under the guidance of the Office of Surface Mining, Reclamation and Enforcement in order to evaluate this process under field conditions. In this study, a series of grout columns were built underwater using standard field procedures and equipment and then evaluated for rate of column formation, angle of repose, and final compressive strength. The purpose of this paper is to describe the testing procedures used and the results obtained during this testing.

MATERIALS AND METHODS

Test Apparatus

For this study, a series of 20 ft-diameter by 4 ft-deep swimming pools were erected to serve as the containers for the grout columns to be formed under water. A wide base diameter was needed to allow the formation of the grout piles without encountering containment problems from the walls of the pool. Each pool was filled to 3 1/2 ft with tap water . Above the pools, catwalks were constructed to serve as supports for the grouting pipes and nozzle. This also permitted observers to look down into the pools during grouting to monitor the rate of column growth and grout dispersion. Where roof contact data were taken, a large rectangular platform was suspended from the catwalk just below the surface of the water and secured so that the grout columns could be formed underneath without displacing the platform upward.

The equipment used for mixing and injecting the grout consisted of a 10 ft³, gas-powered mortar mixer; a truck-mounted , gas-powered peristalic grout pump; a rotary gear pump for silicate supplied from 55 gal drums;

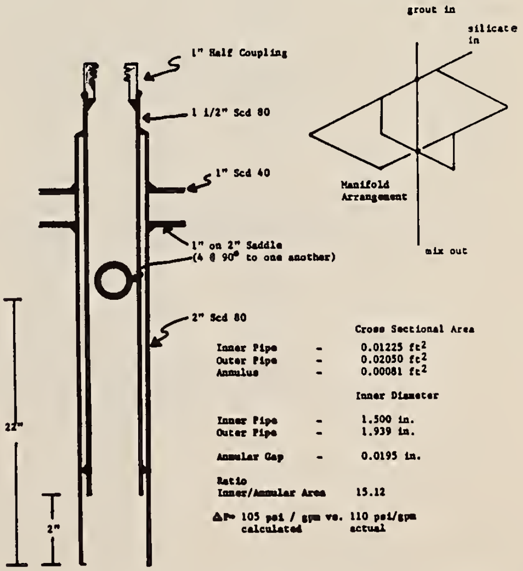

Figure 1. -- Grout nozzle design for silicate delivery.

and an annular nozzle designed to inject the grout mix and silicate simultaneously. The nozzle used was specifically designed to inject a curtain of silicate around the grout stream as it entered the water. Figure 1 details the nozzle design used for these tests.

The grout formulation used for this study consisted of six parts of fly ash to one part cement by volume. The cement used was a Portland type two material and the fly ash a Mercer class F. These components were combined in the grout mixer and tap water was added to bring the total solids of the grout to 72% by weight. The silicate employed was a 3.22: 1 weight ratio (SiO_2 to Na_2O) sodium silicate liquid having a solids content of 37.6% by weight. This material is readily available in the United States and may be obtained in drum or bulk quantities.

The testing procedure used was to mix the grout formulation by hand in a batch mixer and feed it as needed to the grout pump, which delivered the mix to the nozzle on a continuous basis. The pumping rates of the grout were calibrated and maintained by tracking displacement in the pool, pump rotation, and the number of batches mixed. The silicate was delivered to the nozzle via a previously calibrated gear pump.

Experimental Parameters

Because these tests were designed to parallel the types of problems that could be encountered in an actual flooded mine, all the experiments were designed to evaluate this system under those conditions. A total of eight tests were conducted. The test parameters are outlined in table 1. In all cases, the angle of repose of the resulting columns formed was used as the key criterion for performance of the system. The calculation for determining average angle of repose is contained in table 1. The total volume of grout pumped in each test was also measured. In most cases, pumping continued until the grout column broke the surface of the water. Visual observations of grout separation and dispersion were also made, by evaluating the clarity of the pool water during grout placement. Water temperature was monitored throughout the testing to determine if it has an effect on column formation or final compressive strength of the solidified grout.

Table 1. -- Summary of test parameters.

TEST	FLYASH:CEMENT: WATER:SILICATE	FLOW RATE GPM	COMMENTS
1	6:1:3.34:0	8.7	Control
2	6:1:3.34:1.16	8.7	Normal grout with silicate
3	5:1:5:1.24	8.7	Low-solids grout with silicate
4	6:1:3.34:1.12	11.6	Test 2 with increased flow rate
5	6:1:3.34:1.50	11.6	Test 4 with grout tremied in place
6	6:1:3.34:1.16	13.1	Test 5 with column tremied against roof
7	6:1:3.34:1.50	11.6	Test 4 with acidified water
8	6:1:3.34:1.50	11.6	Test 4 with no water in pool

Another variable evaluated was nozzle placement and the method used for constructing the columns. In the early tests, the grout nozzle was located just below the surface of the water causing the grout to free fall through the water before reaching the pool floor and starting column formation. This type of delivery accelerated the separation of the grout components. For the later tests, the grout was tremied in place by locating the nozzle just above the pool floor and slowly raising it as the column gained height. This technique enhanced column formation and limited grout dispersion.

Once the columns had been formed in the pools, they were allowed to age for 1 or 2 days, after which the pools were drained and the resulting piles were measured and photographed. Sample blocks were cut from each column from the center of the pile. A block 1 ft by 1 ft by 1.5 ft was taken from each and sealed until test samples could be made and evaluated for compressive strength, following ASTM procedures. Strength measurements were taken at 7, 14, and 28 days after column formation for each experiment, and measurements were made in triplicate.

RESULTS AND DISCUSSION

A summary of the operating conditions and results of the eight tests performed during this study are shown in table 2. Table 3 reports the compressive strength results for the samples taken from each grout column and figure 2 displays these results graphically. A short description of each test follows.

The first test run during this study represents a control with no silicate being delivered to the grout nozzle. A grout mix at 72% solids was pumped into the filled pool at a rate of 8.7 gpm. The nozzle was positioned 6 inches below the water surface, and the grout stream fell 3 ft through the water before reaching the bottom to start column formation. The total pumping time was 2 hours and 20 minutes, and a total of 6.2 yd^3 of grout was pumped.

Immediately upon starting the pumping the pool water became too

Table 2. -- Summary of operating conditions and results.

Test	Water Temp., Deg. F	Water pH	Nozzle Height, Inches	Grout Flow Rate, gpm	Grout Pressure, psig	Grout Silicate Ratio, By Volume	Silicate Pressure, psig	Volume Pumped, yd^3	Pile Height, Inches	Average Angle of Repose* Deg.	Comments
1	62	8.2	36	8.7	300	0	NA	6.2	18	5	Control, no silicate
2	57	8.2	35	8.7	350	7.9	150	5.7	42	33	Normal grout
3	62	8.3	36	8.7	300	7.9	150	6.2	36	7	Low-solids grout
4	66	11.2	30	11.6	400	9.2	160	6.2	40	53	Higher flow rates
5	51	11.1	12	11.6	350	6.9	195	5.7	43	39	Tremied pile
6	52	10.3	12	13.1	450	7.9	200	6.2	48	45	Tremied against roof
7	55	2.7	12	11.6	450	6.9	200	6.2	42	35	Acid mine test
8	NA	NA	36	11.6	400	6.9	200	3.7	52	36	Pouring pile into air

*Average angle of repose is calculated by taking the arctangent of the following quotient:

$$\frac{\text{Height of the pile from the point it begins to slope upward}}{\text{Diameter of the pile from where it begins to slope upward LESS the diameter of the plateau at the top of the frustum}}$$

Table 3. -- Compressive strength test results.

Test	7 Day	14 Day	28 Day	Test	7 Day	14 Day	28 Day
1	125	175	400	5	250	325	600
	113	200	450		200	400	525
	100	213	375		238	363	550
Mean	112.7	196.0	408.3	Mean	229.3	362.7	558.3
Std Dev.	10.2	15.8	31.2	Std Dev.	21.3	30.6	31.2
2	425	500	625	6	350	500	700
	300	525	675		438	625	725
	375	575	700		413	550	713
Mean	366.7	533.3	666.7	Mean	400.3	558.3	712.7
Std Dev.	51.4	31.2	31.2	Std Dev.	37.0	51.4	10.2
3	213	325	500	7	238	275	750
	225	275	550		188	363	786
	225	350	525		175	325	825
Mean	221.0	316.7	525.0	Mean	200.3	331.0	787.0
Std Dev.	5.7	31.2	20.4	Std Dev.	27.2	36.0	30.6
4	525	650	875	8	225	300	875
	500	700	750		213	338	813
	575	638	900		188	313	838
Mean	533.3	662.7	841.7	Mean	208.7	317.0	842.0
Std Dev.	31.2	26.8	65.6	Std Dev.	15.4	15.8	25.5

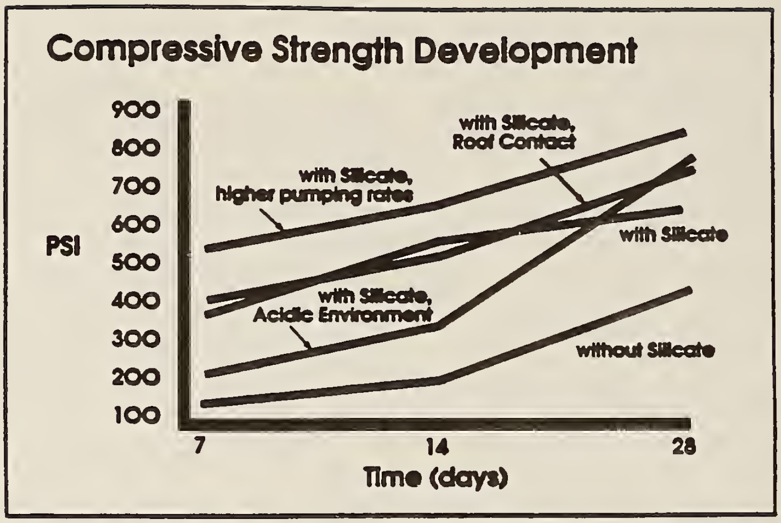

Figure 2. -- Change in compressive strength over time for columns constructed under conditions as shown.

cloudy to see the formation of the pile. This reduction in water clarity indicated that the fly ash from the grout mix was separating out and dispersing. Column formation had to be monitored by probing the grout gently with a pole continually through the test. In this test the grout column never reached the water surface.

After two days, the pool was drained and the pile measured. The column formed was 18 inches high at the center and had an average angle of repose of 5 degrees. The only solidified portion of the column was a small cylinder of grout 2 ft in diameter at the center of the mass. The remaining material was soft and muddy and was of a different color than the rest of the grout indicating that this part of the mass was mainly fly ash that had separated out. The compressive strength of the set portion of the column reached 408 psi in 28 days.

The second test in this series used the same parameters as the first except that silicate was introduced to the grout at the nozzle. One part silicate was pumped through the nozzle for every 7.9 parts of grout by volume. Total pumping time was 2 hours and ten minutes and 5.7 yd of grout were used.

The pool water remained relatively clear throughout the duration of this test, indicating that the grout was not dispersing into the surrounding water. Later examination of the final column verified this. The grout was found to set within minutes after placement, and the column was able to support a man's weight by the time the pumping was completed.

After draining the pool two days later, the grout column was measured and found to have an average angle of repose of 33 degrees. Total height of the column was 40 inches, and the pile was slightly concave on the sides. The entire volume of grout had set, and the final compressive strength was 667 psi after 28 days for this test.

The third test evaluated the effects of silicate on a low-solids grout mix (60% by weight) with an increased cement to fly ash ratio. The proportion of cement to fly ash was increased to enhance the final strength of the set column. A total of 6.2 yd^3 of grout was pumped at a rate of 8.7 gpm, and a grout to silicate ratio of 7.9:1 by volume was maintained. A 36-inch-high column with an average angle of repose of 7 degrees resulted. This column never reached the water surface.

The addition of silicate to this grout mix did enhance the viscosity of the grout stream, but did not significantly improve the average angle of repose of the final mass. The final compressive strength was found to be only slightly better than the control sample (525 psi vs 408 psi). Based on these results, it was concluded that silicate had only a marginal benefit for a low-solids grout mix. The remainder of the tests were all run using a 72% solids grout mixture.

For the fourth test, a higher grout flow ratio was used to determine the hydraulic limitations of the grout nozzle. The increase in grout flow rate to 11.6 gpm resulted in a decrease in grout to silicate ratio. This ratio was 9.2:1 by volume. A total of 6.2 yd³ of grout was pumped, and the test lasted 1 hour and 50 minutes.

There were no adverse effects from decreasing the grout to silicate ratio. The grout mix did not separate as it fell through the water, and the resulting column had an average angle of repose of 53 degrees. The column had a height of 40 inches and was completely solidified throughout the mass. Increasing the grout flow rates seemed to improve the column formation by enhancing the mix of the grout and producing a more uniform mixture. Compressive strength of the column was 842 psi at 28 days.

For the fifth test, 5.7 yd³ of grout was pumped into the pool at a rate of 11.6 gpm. In this test, the grout was tremied in place. The nozzle was lowered into the pool to a height of 12 inches from the bottom, and the column was allowed to grow until the nozzle was buried within the grout. The nozzle was then raised as the pile gained height. Pumping continued until the column broke the surface of the water.

This method permitted a much wider column to be formed. The resulting mass had a height of 51 inches and was 3 ft across at the top. The angle of repose was 39 degrees, and the 28 day compressive strength was 558 psi. The benefits of this method of column construction were very notable. Grout dispersion was strictly curtailed, and the rate of column formation was increased.

The sixth test concentrated on using the previous technique to actually build the column up to a roof and provide a substantial area of contact. A grout flow rate of 13.1 gpm was used, and the test required 6.2 yd³ of material.

The resulting column had an average angle of repose of 45 degrees, and there was a 4-ft-diameter area of roof contact. Contact at the roof was even and level and the platform was well supported along the interface. Final compressive strength at 28 days was 713 psi.

Test seven was conducted in water that had been adjusted to a pH value of 2.7 with sulfuric acid (95%). The standard grout formula was pumped into the pool following the same procedure as test 5. The grout flow rate was 11.6 gpm, and the grout to silicate ratio was 6.9:1 by volume. A total of 6.2 yd³ of grout was pumped during this test.

The reduced pH value of the pool water seemed to have no effect on the grout mix or the rate and shape of column formation. Column height reached 42 inches, and the average angle of repose was 35 degrees. After 24 hours, the pool water was tested for pH value before draining and was found to have increased to a value of 2.9. This slight increase indicates that the silicate barrier was protecting the grout from deterioration by the acid otherwise the pH value would have increased to a much higher level due to the alkaline nature of the grout components. Final compressive strength was also high (787 psi at 28 days) also indicating that the acid did not affect the grout.

The final test was run in a dry environment following the procedure used in test 2. Grout and silicate were pumped through the nozzle at rates of 11.6 and 1.7 gpm, respectively, and the nozzle was suspended 3 ft from the pool bottom. The nozzle tip was buried within 20 minutes of the start of the experiment and once buried the grout was found to follow the path of least resistance, flowing out of fissures in the growing pile and forming uniformly around the nozzle. The absence of water made observation of the column formation easier.

A total of 3.7 yd³ of grout was used to form a column 52 inches high with an average angle of repose of 36 degrees. Final compressive strength at 28 days was 842 psi.

CONCLUSIONS

The results of the tests performed in this study demonstrate the dramatic effect sodium silicate has on the construction of grout columns in water. During this study we found that the çontrol column, built using 6.2 yd of grout without silicate present, attained a height of only 18 inches and had an average angle of repose of 5 degrees. In the other trials, with silicate being introduced at the nozzle, the grout was able to be formed into columns having a high angle of repose, maximizing structure height while minimizing raw material usage. The average angle of repose of the silicate-enhanced columns was at least 5.5 times greater than the control, and all columns achieved a height of 36 inches or more. This is double the height found in the control. The inclusion of silicate into the grouting operation also was found to enhance the stability of fresh grout placed underwater, preventing separation of the grout components while improving its stiffness and self-supporting qualities. In addition, silicate was found to improve the rate of grout setting and the final compressive strength of the hardened material. All of the factors combine to eliminate most of the problems associated with building support structures in a flooded environment.

Throughout these trials, the average angle of repose of the constructed columns was used as the key criterion of grout performance. Using this measurement, the total volume of grout needed to build a support column of any specific height can be calculated. One problem with using this value is that final column height can significantly affect the average angle of repose measured. Figure 3 shows the final shape of the column built in test 6 and illustrates how the average angle of repose relates to actual column geometry. Columns formed using the silicate/grout process all display this same general configuration. During column construction, a wide base is established at a fairly low angle of repose until the grout mix has gained enough strength to support its own weight. Once the base has stabilized, a column can be built of fresh grout without slippage or collapsing of the structure. Since silicate accelerates the set time of the grout, the amount of material pumped before a stable base is established is reduced. The average base height for the columns constructed with silicate present were 1 ft or less. Since the average angle of repose is calculated using base width and total column height, the concave nature of the structure is not taken into consideration. The greater the height of the column, the greater the discrepancy will be in calculating grout volume needed using average angle of repose.

This type of column configuration was only noted when silicate was used during grouting. In the control test, there was no deviation in actual column geometry from the average angle of repose measured. Without the benefit of silicate, the mix was unable to form a firm base quickly due to dilution of the grout by the surrounding water. This caused the grout to settle into a low slope pile to achieve stability. There was no concavity noted in this formation.

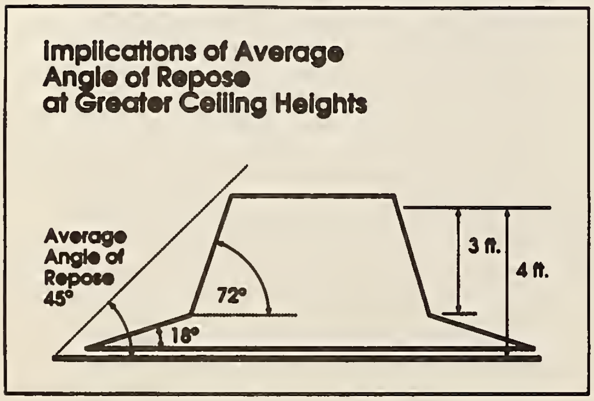

Figure 3. -- Average angle of repose for column 6 as related to actual column geometry.

This difference in column formation is due to the gel barrier formed around the grout stream during pumping. Columns built with silicate all had a thin layer of gel on the outside surface when the pools were drained. The presence of this gel could also be seen inside the columns when they were sectioned to obtain samples for the compressive strength measurements. The formation of this barrier not only limited dilution of the grout by the surrounding water, but prevented the separation of the fly ash and cement components. When using silicate, the pool water remained relatively clear for the duration of the pumping. In the control test, the water immediately became turbid enough so that column formation could not be monitored visually. Examinations of the final columns after the water had been drained also corroborated the fact that the silicate prevented separation of the grout components. In the control test, the column formed was solid only at the center of the grout mass. Fly ash was noted to have settled all along the bottom of the pool in a layer a few inches deep, and the surface of the grout pile was tan indicating that the majority of the material there was fly ash. The columns formed using silicate were found to be uniform in color and in strength throughout the entire mass. There was also an absence of the fly ash layer noted on the pool bottom in the control.

Other than the presence or absence of silicate, no other variable tested had an effect on column slope or angle of repose except for the solids content of the grout mix. In test 3, the solids content of 60% by weight resulted in a very low slump mix (11.75 inches). This grout was sufficiently thin enough to reduce the positive effects of the silicate and resulted in an angle of repose of only 7 degrees for the column formed. Therefore, this mix would not be recommended for field use. Other variables did not affect column geometry; Differences in grout flow rates, grout to silicate ratio, nozzle location, water temperature, or pH value of the water did not contribute to final column shape.

Not only was silicate found to be beneficial in column formation, it also enhanced the ultimate strength of the set grout. Based on a statistical analysis of the data generated, it can be inferred, with 90% confidence, that in all tests the silicate improved the final compressive strength of the columns. Based on the data, silicate has the greatest impact on the seven day strengths of the grout. Columns formed with silicate were able to support a man's weight immediately while the control required two days to attain any appreciable amount of load bearing capacity. The benefit of this is that columns formed using this technique would immediately serve to stabilize the mine overburden and limit subsidence.

The flow rates of the grout during pumping did seem to have an effect on column strength. As flow rates increased, the residence time of the grout in the pump and the lines was reduced. This limited the formation of early bonds within the grout that would be broken during pumping and placement. In some cases, these bonds may not be reformed once broken which could theoretically reduce final strengths. More importantly, the higher flow rates improved the mixing of the grout and silicate during placement. Silicate is known to have a positive benefit on the final strengths of cements, and by increasing the amount of silicate incorporated into the column matrix, the resulting strength was improved. This should improve the durability of columns formed in a mine water environment especially since the silicate improves the acid resistance of the grout.

The results of this study indicate that the use of silicate will have a substantial impact on the economics associated with stabilizing a flooded mine. When silicate is used the volume of raw materials needed to support the overburden are significantly reduced. Table 4 outlines the cost for building a 6-ft-high column with and without silicate. For this analysis an average angle of repose taken from the seven tests using silicate is compared with the angle of repose measured for the control column. We assume no concavity for the silicate-formed columns and also include the results from test 3 which reduces the angle of repose value to 27.5 degrees, well below that measured for all the columns formed using the 72% solids grout mix.

Table 4. -- Raw material costs for column construction.

	CONTROL	AVERAGE OF ALL SILICATE TESTS
Average Angle of Repose	5°	27.5°
Column Height	6 ft	6 ft
Column Base Diameter	243.2 ft	29.1 ft
Column Frustum Diameter	6 ft	6 ft
Column Volume	1244.4 yd^3	61.5 yd^3
Cost of Grout, \$/yd^3	\$32.92	\$63.57
Total Raw Material Cost, \$/Column	\$40,965.65	\$3,909.52

As can be seen from these data, it would take 1244.4 yd^3 of grout to obtain a column 6 ft high without using silicate. At a cost of \$32.92/yd^3 of grout, it would take almost \$41,000 in raw materials alone to build one support column. With silicate, at an average angle of repose of 27.5 degrees, the volume of grout needed to attain 6 ft in height is reduced to 61.5 yd^3. Even with the increased cost associated with including the silicate, the total cost in raw materials is less than \$4,000. Based on this conservative estimate, a silicate-enhanced grout appears to reduce raw material costs by a factor of ten.

Other cost savings should be realized because silicate will reduce the total time and labor costs associated with any one job. By reducing the total volume of grout placed to form a column, the time it takes to complete the stabilization is reduced. Labor costs would then be reduced as well as the equipment rental costs for the total job. Silicate also will allow for columns with adequate roof contact to be built more reliably. This would decrease the need for repeat treatments and should eliminate the loss of raw materials to inadequate columns.

The addition of silicate to the grouting process was found to be simple and required little as far as additional equipment is concerned. The nozzle used for introducing the silicate into the process is relatively straightforward and easy to construct at minimal expense. An additional pump is needed for the silicate delivery, but the cost of this piece of equipment is inconsequential compared to the cost savings realized by using this technology. Specific equipment costs are available from the authors.

SUMMARY

A series of columns were built underwater with and without silicate. The control column formed without silicate had an average angle of repose of 5 degrees and displayed poor compressive strength throughout the structure due to segregation of the grout components. Columns formed when silicate is used in the process were on average 5.5 times greater in angle of repose than the control and were 48% higher in compressive strength. An economic analysis comparing the costs for building a 6-ft-high column with and without silicate shows that the raw material costs alone are reduced by a factor of ten when this technology is used.

ACKNOWLEDGMENTS

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EFFECTS OF THE NUMBER OF LATERAL ROOTS ON FIRST-YEAR SURVIVAL OF RED OAK SEEDLINGS ON STRIP-MINE SPOIL

Alban-Snyder, T. A. and Wacker, S. E. (Foresters, Pennsylvania Bureau of Forestry). Red oak (Quercus rubra) seedlings from the Pennsylvania Bureau of Forestry nurseries were graded into three treatment levels by the number of lateral roots 1 mm in diameter or greater. Those in the "low" level had 0 - 5 lateral roots, "medium" had 6 - 11 roots, and "high" had 12 or more lateral roots. Seedlings from the three treatment levels were randomly selected, planted, and identified with a permanent metal tag. The experiment was replicated on reclaimed strip-mine sites in Indiana and Westmoreland Counties, PA. Three blocks were established at each site using 225 trees/block. Survival, height, and stem caliper were measured 1 year later and found to be significantly different for the three treatment levels on both sites. The Westmoreland site had heavy grass cover, and 35% of the seedlings were chewed by rodents. "High" seedlings survived the damage better than "low" or "medium" seedlings. Twenty-one percent of the seedlings at the Indiana County site were frost-heaved. Seedlings with a "high" number of lateral roots were less likely to be frost-heaved and more likely to survive heaving, than "low" or "medium" seedlings. It appears from this study that seedlings with more lateral roots survive and recover better from damaging conditions than those with fewer lateral roots.

Additional Key Words: red oak, strip-mine spoil, lateral roots, bareroot seedlings, grading, frost-heave, rodents.

TREE PLANTING AND MONITORING ACTIVITIES OF THE REGION OF SUDBURY LAND RECLAMATION PROGRAMME, CANADA

Beckett, P. J. (Assistant Professor, Biology Department, Laurentian University, Sudbury, Ontario, Canada; Chairman, Tree Planting Subcommittee, Vegetation Enhancement Technical Advisory Committee, Region of Sudbury). During the past 10 years the Region of Sudbury Land Reclamation Programme has reclaimed 2,700 ha of acid, metal-contaminated land. First, designated areas are treated with surface application of limestone, fertilizer, and a grass-legume seed mixture. Subsequently, the grass areas are planted with trees at a low rate of stocking. Prime consideration is given to increasing species diversity, attracting wildlife, and creating an aesthetically pleasing landscape. Preference in species selection is given to native species of central Ontario; approximately 20 species have been utilized. Jack Pine (Pinus banksiana Lamb.), Red Pine (Pinus resinosa Ait.), and White Pine (Pinus strobus L.) account for more than half of the 0.75 million trees planted since 1979. A monitoring programme has indicated that Red and Jack Pines have similar growth rates to trees sampled in forest regeneration areas near Sudbury. White Pine is surviving in sites close to the Sudbury smelters, an indication of the improved environmental conditions. Among the hardwood, Red Oak (Quercus rubra L.) shows the best overall performance, and Black Locust (Robinia pseudoacacia L.) increases biomass at a rapid rate in spite of being north of its natural range. Although there is metal uptake into the trees, the levels of Cu, Ni, and Al do not appear to be toxic.

Additional Key Words: revegetation, ecosystem development, habitat creation.

BLAST FURNACE SLAG AS A LIMING MATERIAL FOR MINE RECLAMATION

Beeghly, J. H. (Manager of Product Development, The Standard Slag Company, Younstown, OH). Blast furnace slag, a byproduct of making iron, has been used as a liming product since the 1920s. Research and practice have been mostly with the granulated type, which no longer is available. Current research demonstrates that the more common air-cooled type of blast furnace slag can be an effective liming material. Thousands of tons of slag fines are produced annually in the Ohio River Valley coal-producing area. Blast furnace slag comes from the use of limestone and dolomite as a flux in the reduction of iron ore. Air-cooled blast furnace slag has been found to be similar to limestone in terms of calcium carbonate equivalency. Current specifications in Pennsylvania make it impossible to use slag fines, which even when screened as fine as possible, are still too coarse in size gradation. Because pulverizing the slag fines is not cost effective, this rules out the economical use of slag fines in Pennsylvania. The states of Ohio and West Virginia make allowances for the use of coarser lime materials; the proposed interstate uniform agricultural liming law will permit the use of coarser liming materials. The slag has been used on several abandoned mine reclamation projects sponsored by the Office of Surface Mining Reclamation and Enforcement of the U.S. Department of Interior. A coarser liming material would be advantageous for mine reclamation if additional tonnage is applied, as is allowed in Ohio. The coarser graded material provides a time release effect for neutralizing future production of acid as new pyritic materials are exposed in the reclamation process.

Additional Key Words: agricultural lime, acid soil, blast furnace slag fines.

RECULTIVATION OF SPOIL BANKS DISTURBED BY OPEN-CUT MINING ACTIVITY IN HUNGARY

Szegi, J. (1), Olah, J. (2), Fekete, G. (3), Halasz, T. (4), Varallyay, G. (5), and Bartha, S. (6). ((1) Head of Soil Biology Department, Research Institute of Soil Sciences and Agricultural Chemistry of the Hungarian Academy of Sciences, Budapest, (2) Matraalja Coal Mining Company, Gyongyos, (3) Institute of Ecology and Botany of the Hungarian Academy of Sciences, Vacratot, (4) Green Belt Planning Office of the Pilis State Forestry, Balatonfured, (5) Research Institute of Soil Sciences and Agricultural Chemistry of the Hungarian Academy of Sciences, Budapest, and (6) Institute of Ecology and Botany of the Hungarian Academy of Sciences, Vacratot). Various recultivation processes were studied in the area of the Visonta Open-Cut Mine Enterprise in Hungary. The different recultivation tasks have been integrated with the landscape protection planning, which is responsible for the preservation and enhancement of the landscape. The physical, chemical, and biological properties of spoil which originated from different geological layers were investigated. The recolonization of microorganisms and natural vegetation were studied during the different stages of recultivation. It was found that the development of soils and vegetation were influenced by the pre-mine environment, the physical and chemical characteristics of the spoil, and the intensive human activity at the site. A special soil estimation system was developed to judge the economic usefulness of recultivated spoils. Finally, a rapid, combined recultivation process was carried out in Visonta.

Additional Key Words: reclamation, surface-mine spoil, revegetation, ecosystem development.

SOIL EXTRACTION TESTING TO DETERMINE THE EXTENT OF HEAVY METAL CONTAMINATION

Zahl, E. G. (Civil Engineer, Department of the Interior, Bureau of Mines, Spokane Research Center). Initial results are presented of a current Bureau effort to determine the applicability of a soil extraction test to be used as a screening tool for predicting the suitability of selected rangeland plant species for revegetating acid and heavy metal-contaminated soils. Project areas are located near Red Lodge, MT, and Superfund sites at Anaconda, MT. Research activities included: (1) leaching of study plot soils using various extraction solutions and analysis of leachates for trace element concentrations using emission spectroscopy; (2) collection of samples of interstitial water from the root zone using suction lysimeters and subsequent analysis for element concentrations; and (3) testing of the toxicity of the root-zone environment using bioassays with luminescent bacteria. A statistical comparison is being made of the data from these studies and those previously obtained from costly, long-term revegetation studies. Successful results will lead to a method of determining which plant species are best adapted to surface areas that have various degrees of acid and heavy metal contamination. Such determinations can become important since the degree of contamination can vary considerably from acre to acre, and the proposed method would preclude the need for numerous and costly revegetation studies. The results could be applied to vegetation established to reduce windblown dust and contaminated aquifer recharge waters, as well as to vegetation established for agricultural production.

Additional Key Words: revegetation, acid-contaminated soils.

EVALUATION OF PROCEDURES USED IN FOUR MINE SUBSIDENCE CONTROL PROJECTS

Elder, C. H. (Geologist, USDI-OSMRE-EFO, Pittsburgh, PA). An evaluation was made of the effectiveness of various procedures and materials used to abate abandoned mine subsidence. Four mine subsidence projects were selected: (1) Green Ridge Demonstration Project, Scranton, PA - backfilled with anthracite mine refuse by slurry injection; (2) Watson Hill Subsidence Abatement Project, Fairmont, WV - backfilled with fly ash slurry; (3) Farmington Subsidence Abatement Project, Farmington, WV - backfilled with bituminous mine refuse by slurry injection; and, (4) 70th Street Subsidence Project, Belleville, IL - backfilled with mine refuse by pneumatic/hydraulic injection. Test borings, sampling, and field and laboratory tests were performed to determine lateral and vertical extent of the backfill and physical properties of the materials relating to particle size, sedimentation pattern, strength, and *in situ* bearing capacity. Voids ranging from 1 ft to 6 ft in height were encountered above the backfilled material at all test sites and were sufficient to permit roof collapse and resultant subsidence. Particle size analysis and observed bedding of the backfill materials indicate sorting, grading, and channel deposition rather than radial distribution. Water-saturated mine refuse materials were plastic enough to yield with vertical and lateral pressure as indicated by penetration tests, laboratory analysis, and *in situ* pressure tests. Fly ash remained plastic to fluid having little strength to abate subsidence. An added cementing material may be required for a stable fill capable of supporting overburden. Post-project monitoring of abatement projects is recommended to determine long-term project effectiveness.

Additional Key Words: backfilling, slurry injection, coal refuse, fly ash.

WEST VIRGINIA ABANDONED MINE LAND RECLAMATION

Robinson, N. A. (Project Manager, West Virginia Department of Energy, Charleston, WV). Public Law 95-87 provides funds, through taxes levied on each ton of coal mined, to reclaim abandoned mine sites which pose health and safety hazards to the general public. Only those sites which were abandoned before August 3, 1977, or for which there is no continuing reclamation responsibility are eligible for abandoned mine land (AML) funding. Due to its extensive mining history, West Virginia possesses some of the most severe hazards in the nation, including subsidence, unstable refuse piles, unsealed or improperly sealed mine entries, and underground mine fires. Where homes located above abandoned mine workings are affected by subsidence, exploratory drilling programs are used to reveal the conditions of the mine void, which is then filled with a grout or concrete mixture, stabilizing ground surface movement. Coal refuse piles which are burning can choke narrow valleys with smoke and noxious fumes, and piles which were initially dumped haphazardly over steep hillsides can present a stability problem. Constant erosion introduces acid and sediment loads to the receiving streams. Reclamation involves regrading the refuse material into the stable configuration and controlling surface drainage. Open entries to underground deep mines with decaying roof supports are sealed using a gravel bulkhead to prevent public access. Collapsed deep mine entries can dam up mine drainage until hydraulic head pressure forces a "blowout" or explosive discharge of this drainage. A gravel bulkhead seal with a perforated PVC pipe is installed in the entry to prevent access, provide for the free flow of drainage, and eliminate potential hydraulic head buildup. Underground coal mine fires, a serious threat throughout West Virginia's coalfields, have ignited forest fires that subsequently devoured large acreages of forests and endangered local residents. West Virginia's AML program has extinguished one mine fire to date utilizing a method known as total filling. The West Virginia Abandoned Mine Lands Program has completed over 150 projects, costing 60 million dollars, and successfully abating health and safety hazards on all.

Additional Key Words: mine subsidence, coal refuse fires, slope stability, erosion, mine sealing, mine fires.

CONTROLLED GROUT COLUMNS: A POINT-SUPPORT TECHNIQUE FOR MINE SUBSIDENCE ABATEMENT

Michael, P. R. (1), Lees, A. S. (2), Crandall, T. M. (3), and Craft, J. L. (4). ((1) Geologist, (2) Mechanical Engineer Technician, (3) Supervisory Physical Scientist, (4) Geologist, Office of Surface Mining Reclamation and Enforcement, Pittsburgh, PA). Mixtures of fly ash, sand, gravel, and cement are commonly used to fill abandoned room-and-pillar coal mines in order to prevent or abate surface subsidence due to mine void closure. However, the large volume of material required to provide support to mine pillars, overlying strata, and surface facilities (e.g. buildings, roads, and utilities) is extremely costly. Controlled placement of the material and sufficient roof contact are often difficult to achieve. To maximize control of the emplaced material and improve roof contact, a method for the remote construction of cylindrical columns within the mine void has been developed. Nylon fabric bags are attached to the injection pipe, inserted through a borehole into the mine void, and subsequently filled with a fly ash/cement mixture. Cylindrical columns 6 ft in diameter and 12 ft high have been successfully constructed at a reclamation project site in Yorkville, Jefferson County, OH. Further development is needed to study: (1) improved bag design, (2) optimum fill material, (3) grout pumping rates and pressures, (4) remote monitoring of column construction, (5) physical limitations of the technique, and (6) remote installation of the support bag.

Additional Key Words: mine stabilization.

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